INTERNATIONAL SUSTAINABILITY UNIT

WHAT PRICE RESILIENCE?

TOWARDS SUSTAINABLE AND SECURE FOOD SYSTEMS

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CLARENCE HOUSE

Producing enough food of a sufficient quality to allow every man, woman and child on our planet to pursue a happy and healthy life is increasingly becoming a challenge. Today, over one billion people – one seventh of the world's population – are hungry and another billion suffer from 'hidden' hunger in as much as they are unable to access sufficient nutrients and essential vitamins. But, simultaneously, over a billion people in the world are now considered to be overweight or obese. It is surely an increasingly insane picture that, in one way or another, half the world finds itself on the wrong side of the food equation.

It appears that the causes of this paradox are neither simple nor easy to solve. Indeed, when we talk about food production (whether of crops, meat or fish) we are talking about deeply complex and interrelated systems which are, in many cases, increasingly showing signs of stress. It is already becoming apparent that food, water and energy security are intricately bound together, as too is their relationship with stable economic and political systems. Over the last twenty years much has been written about how we could generate economic growth that is environmentally, economically and socially sustainable, yet perhaps a more precise way of framing the question might be to ask how we can create economies that ensure environmental, economic and social resilience and the capacity to adapt?

What does seem certain is that the difficulty of achieving food security is only going to intensify. The United Nations Food and Agriculture Organization estimates that the global demand for food will rise by seventy per cent between now and 2050. The world somehow has to find the means of feeding a staggering 220,000 new mouths every day. At the same time, our precious natural resources – our oil, water, minerals, biodiversity and even ecosystems – are subject to increasingly fierce competing demands. And all of this, of course, has to be set against the impact of climate change. Already yields are declining in Africa and India where crops are failing to cope with rising temperatures and fluctuating rainfall. In the face of the very challenging circumstances of the twenty-first century, it does seem to be imperative to ask whether the way in which we produce our food is actually fit for purpose.

Knowing this, I felt I should do what I could to help find some way to navigate through these incredibly complicated issues. Drawing upon the experience I have gained working with the N.G.O. community and the private sector, I formed my International Sustainability Unit to help facilitate consensus on how to resolve some of the key environmental challenges facing the world.

As a first step, the I.S.U. has set out to examine the economics and impacts of current food production systems and to assess whether they are likely to be resilient to the challenges of the coming decades. The I.S.U.'s initial findings, which are described in this report, illustrate that at the moment many farmers and fishers, who are frequently heavily reliant on public subsidies, struggle to make a profit while contributing substantially to the depletion of natural capital. In most cases, the market price of food doesn't include the environmental and social costs of its production. At the same time, many of these systems are vulnerable to the types of risks and disruptions that contributed to the recent volatility on food markets and that are likely to intensify in the future.

However, there is, I believe, considerable room for hope, not least because the report's case studies show that practical ways to produce our food and manage our marine ecosystems in a more sustainable and resilient way do already exist and could be taken to scale. Moreover, surely there must be quite simple solutions to problems such as the wastage of forty per cent of food post-harvest in developing countries, or the possibility of dramatically increasing the knowledge of the smallholders who produce seventy per cent of the world's food.

The urgency of moving to more sustainable and resilient forms of production cannot be underestimated. Genuinely sustainable food production maintains the resilience of the entire ecosystem and puts Nature back at the heart of the equation. If we are to make our agricultural and marine systems, and therefore our economies, more resilient in the long term, then we have to recognize that food production is an integral part of a wider system. The need then, it seems to me, is to design policies across all sectors that bring the preservation of natural capital to the fore.

Although the task is daunting, I am encouraged by what the I.S.U.'s work has revealed, not least because it confirms what I have believed for nearly thirty years – that if we want to improve food security, we have to deepen our understanding of the relationship between food, energy, water and the environment. By examining food production in an integrated fashion, not simply by its physical productivity or economic profitability, but rather by the diverse array of economic, environmental and social costs and benefits that it creates, it is possible to untangle the complexities of the present system. By doing so, it will be possible to create a set of incentives and markets that will ensure food security, improve public health, expand rural and coastal employment and enrich our quality of life.

Executive Summary

Context

The Prince's Charities' International Sustainability Unit (ISU) was created to help build consensus on solutions to some of the major environmental problems facing the world. Over the past year, the ISU has commissioned research on the sustainability and resilience of food systems and begun to work with other organisations on these issues. The focus has been on food production (although it is recognised that distribution, access and affordability are just as important to food security). This document sets out some of the ISU's initial findings.

A food system in crisis

The world is experiencing a food crisis. Rapidly rising food prices have sparked riots, contributed to political instability and caused the number of malnourished people to rise to 1 billion. World food markets have experienced greater volatility than at any time since the 1970s, a sign that supply is struggling to keep up with demand.[1]

A number of recent studies have attempted to explain the volatility in global food markets. They have identified exacerbating factors such as trade restrictions, financial speculation, currency movements and lower food reserves. They have pointed to growing demand caused by an expanding population and biofuels policies, as well as supply constraints caused by rising energy costs, water depletion, extreme weather events, ever increasing competing pressures on land use and under-investment. All of these have played a part. But the ISU believes that the current crisis is also a manifestation of deeper, long-term trends associated with the linkages between food and energy, the erosion of natural capital, climate volatility, and poverty, inequality and under-development in large parts of the world.

Food security and food price volatility are now major items on the agenda of policymakers. Many proposals have been put forward to deal with the crisis, mostly focused on increasing transparency, controlling speculation, improving the functioning of global markets or lessening the impacts on the most vulnerable. These can play a role, in the short-term, but future crises will only be avoided if the underlying challenges are addressed. This is because the underlying factors that led to the recent food crisis are likely to intensify in the coming decades.

Risk and resilience

There are four key risks that challenge the global food system today and that are likely to increase if we continue along a 'business as usual' path.

1. Exposure to energy and input prices. Modern agriculture is highly dependent on non-renewable resources such as oil, natural gas and mined phosphates. Although these inputs are unlikely to 'run out' in the next fifty years, many will become scarcer and more expensive. Volatility in energy and other commodity markets will be felt in food markets as well. The growth of biofuels will strengthen the linkages between the two markets further.

2. Erosion of natural capital. Agricultural systems and the over-harvesting of wild fisheries are depleting natural resources at an alarming rate, approaching ecosystem limits, and, in some cases, coming close to ecological collapse. There are limits on the amount and quality of land available, magnified by soil degradation and urban conversion. Finite water reserves are being depleted by unsustainable irrigation practices, while water quality is affected by industrial, urban and agricultural use. Food production is vulnerable to pests, diseases, biodiversity loss and the failure of ecosystem functionality, often brought about by polluting or extractive agriculture or fisheries systems.

3. Extreme weather events and climate change. One of the most visible causes of disruption to world food supplies over the past five years has been extreme weather events. This could be a taste of what is to come. Climate change is predicted to threaten agriculture and fisheries in large parts of the world.

4. Poverty, inequality and underdevelopment. Extreme poverty and low agricultural productivity in developing countries turn volatility in global markets into a crisis of survival for millions. Ecosystem degradation and the damaging effects of climate change are likely to be concentrated in these countries, exacerbating the challenge. At the same time, growing demand for resource-rich diets, as well as pressure on land for biofuels and non-food crops, are likely to increase global imbalances and threaten food access in the poorest countries.

These risks are inter-linked and often reinforcing, which means that they require an integrated response. For too long there have been two separate debates about the future of the global food system, one focusing on sustainability and the environment, the other on food security and hunger. The events of the past five years, and the stresses that loom on the horizon, show that these cannot be separated. Sustainability and food security are two sides of the same coin. One is not possible without the other. A truly resilient food system will encompass both.

The true costs of food

In order to better understand how some of these risks might affect individual food systems, the ISU commissioned

1 FAO, (2011). *Food Price Index.*; Blas, J. (2011) In Depth: The Global Food Crisis. *The Financial Times*

research on agricultural case studies from the UK, USA, India, Brazil and Ethiopia and fishery case studies from Thailand, Senegal and the Northeast Atlantic. The goal was to understand the 'true' economics of food production systems once subsidies and environmental impacts were taken into account, while assessing their vulnerability to future shocks and disruptions.

This research revealed that during the periods studied (generally before the recent food price increases) most food production systems struggled to generate private profits for producers. Moreover, apart from Ethiopia and Brazil, most of the systems were heavily reliant on public subsidies: on average subsidies represented 18% of the value of the food produced. In pure financial terms, therefore, these systems did not produce good value for society.

When the environmental costs were calculated, the situation looked even worse. All the food production systems were found to produce negative environmental 'externalities', such as greenhouse gas emissions, air and water pollution, and biodiversity loss. Many of the systems were found to deplete the soils, water and ecosystems on which they depend. These systems appeared to be mining natural capital and pushing the costs onto society or future generations.

Many of the food production systems appeared vulnerable to future risks and shocks. Under 'business as usual', water depletion, climate change, over-exploitation of fishing stocks and heavy reliance on energy-intensive inputs were likely to result in greater volatility of output and pricing in the next forty years. The most vulnerable systems were in developing countries, the places that are set to experience the most growth in food demand.

The research indicates that the market price of food often does not reflect the 'true costs' of its production. For example, if public subsidies and environmental impacts were taken into account, the 'true cost' of $100 of farm produce in the UK may be closer to $145. For $100 of Brazilian beef the figure was estimated at between $166-231 (largely because of its role in deforestation) and for $100 of Thai farmed shrimp it was $134. It is also unclear whether these systems delivered sufficient social benefits, such as improved worker incomes and welfare to justify these high costs.[2]

Towards sustainable and resilient food systems

The world needs food systems that deliver a range of economic, environmental and social goals, while being resilient to risks and disruptions. The good news is that there are plenty of examples of systems that do just that. The case studies prepared for the ISU point to alternatives that may represent 'no regret' moves. There is also a growing body of literature from around the world containing examples of successful 'agro-ecological' approaches. What these systems will look like will depend on local circumstances, but some principles can be discerned. More sustainable and resilient food systems are likely to be based on a deeper understanding of biology and ecology, on working with natural processes as much as possible, on limiting use of external fossil fuel-based inputs, and on maintaining species diversity.

Strengthening resilience should be a key priority. Resilience must operate at multiple scales, from the farm or fishing boat, to the village, watershed, region, nation or global trading system - at each level complexity increases. Adaptive capacity will be key. Food systems that are diverse, modular and flexible are more likely to have the adaptive capacity that will be needed to overcome the challenges of the coming decades. The focus of policy should be broadened from growth and efficiency to risk, recovery and flexibility. Better ways of collecting and sharing information will be needed so that policymakers become aware of potential stresses in good time and understand how actions affect the system.

Substantial opportunities also exist to reduce food waste, which accounts for at least 30% of all food produced.[3] In developing countries waste tends to occur soon after harvest or during the transport, processing or storage of food; in industrialised countries most waste occurs further down the supply chain, at the point of the consumer. There may also be opportunities to alter the type of food that consumers demand, which could reduce the burden of obesity and poor nutrition on societies. Changes in these parts of the food system could mitigate any higher production costs associated with more sustainable practices.

The 'size of the prize' is great. Recent research by the UN Environmental Programme indicates that investing in the 'greening' of agriculture and fisheries, compared to continuing with 'business as usual', would produce $293 billion more economic value-added per year by 2050, an 11% increase. 'Green' agriculture and fisheries would be more productive, less polluting and would also create more jobs.[4] The World Bank estimates that the transition to sustainable fisheries management alone could generate $50 billion more in global GDP each year.[5]

A 21st century revolution in agriculture and fisheries management would also be a tool for poverty alleviation: the World Bank estimates that agriculture is twice as effective at reducing poverty than growth in other parts of the economy. Smallholder farms, which already provide 70% of all food, should play the most important role in this revolution. The transition to sustainable and resilient food systems will also have fiscal benefits and facilitate balanced urban and rural development.

2 Unless otherwise noted, please refer to Annexes A & B for further information

3 Foresight. (2011) *The Future of Food and Farming: Challenges and Choices for Global Sustainability*. London, The Government Office for Science

4 UNEP. (2011) *Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication*. www.unep.org/greeneconomy, UNEP

5 World Bank, (2009). *The Sunken Billions : The Economic Justification for Fisheries Reform*. Washington

The ISU suggests two sets of actions that could assist the transition towards more sustainable and resilient food systems. The first is the development of analytical tools to help policymakers and food producers assess the performance of agriculture and fisheries against multiple goals: economic productivity, environmental impacts, social costs and benefits, and resilience. Existing tools already address part of this challenge, and many others are under development, but what is needed is an integrated approach that allows policymakers to look at food systems as a whole and to weigh up different options. This will require a well-considered methodology, which places social and environmental factors within an economic context, as well as better data, especially on ecosystem impacts.

The second suggested action is to find ways to change the economic framework within which food producers currently operate. This could include new market mechanisms, taxes and regulations, or incentive schemes for farmers and fishers, which could help to internalise the costs of natural capital depletion. Transitional finance may be required to help producers meet upfront investment costs – this could take the form of concessional credit or innovative financing mechanisms involving the public and private sectors. In many countries, the reform of public subsidies will play a critical role. Currently, many subsidies encourage unsustainable activities; instead, public money should be used for public goods. 'Smart' subsidies can play an important part in creating the right incentives for food producers.

Next steps

The ISU is considering three sets of activities that it could undertake in the future. These include supporting the further development and integration of analytical tools that would help policymakers measure and strengthen the resilience of food systems; working with the private sector to identify ways in which it can support the scaling up of sustainable production methods; and continuing with a more focused programme on fisheries. The ISU will continue to work with a wide range of stakeholders who are supporting the transition to more sustainable and resilient food systems.

1 About the ISU

The Prince's Charities' International Sustainability Unit (ISU) seeks to build consensus around solutions to some of the world's key environmental challenges. This report sets out some initial findings on the sustainability and resilience of current food systems.

1.1 Background

HRH The Prince of Wales established the International Sustainability Unit (ISU) to facilitate consensus on how to resolve some of the key environmental challenges facing the world – these include food security, ecosystem resilience and the depletion of natural capital. The ISU works with governments, the private sector and non-governmental organisations, helping to strengthen partnerships between these sectors.

The ISU hopes to build on the success of The Prince's Rainforests Project, which in 2008 and 2009 helped catalyse a process that led fifty governments to agree the REDD+ Partnership, an intergovernmental platform that is scaling up actions and finance to reduce tropical deforestation. As a legacy of this project, the ISU still works with agribusinesses and NGOs in Brazil, Indonesia, Malaysia and West Africa to find ways to make agricultural development compatible with forest conservation. Since 2010 the ISU has broadened its scope to look at agriculture, fisheries and food systems more generally.

1.2 The ISU agriculture and fisheries programmes

The ISU has sought to understand some of the major challenges facing the global food system and to identify ways that it could be made more sustainable and resilient. First and foremost, this has meant studying the many initiatives on food security being conducted by governments, multi-lateral agencies, research institutes and think tanks around the world. Second, the ISU has commissioned research by external consultants on the economics of current and alternative agricultural systems in five countries. In addition, the ISU has consulted with a broad range of experts, sharing preliminary findings and exploring where consensus might exist for a programme of action.

In parallel, the ISU has conducted detailed research on marine fisheries. As well as consulting widely with experts and other organisations active in this field, the ISU has commissioned two pieces of research from external consultants. One analyses 20 case studies of fisheries around the world that have transitioned towards sustainable management. The other seeks to understand the economics of 'business as usual' versus sustainable alternatives in three specific fisheries. This document incorporates some of the key findings from the ISU's fisheries work, but more detail can be found in a supplementary ISU report; *Transitioning to sustainable and resilient fisheries*.

The ISU recognises that many organisations have produced substantial pieces of research on the challenges faced by food systems and the required response. These include, *inter alia*, the work of Foresight and the UK's Government Office of Science; the International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD); the UN's High Level Task Force on the Global Food Security Crisis; the UN Environment Programme's 'Green Economy' initiative; and key reports on agriculture, fisheries and development by the World Bank, the International Fund for Agricultural Development, the UN's Food and Agriculture Organization, the UN's Conference on Trade and Development, Chatham House, IFPRI, and others. The ISU does not wish to rival or replicate this excellent work. Instead, the ISU hopes to highlight some common themes from these initiatives and to identify points of consensus that could lead to action.

1.3 Objective of the document

This document presents the findings of the ISU's research, while also drawing on the conclusions of other initiatives. It attempts to assess the challenges faced by the global food system, to understand the economic incentives that drive current practices and to articulate some principles that might guide the transition to a more sustainable and resilient food system. It also suggests some analytical tools and practical actions that could support this transition, if further developed.

The focus of the ISU's research has been on production systems in agriculture and the harvesting of marine fisheries, i.e. on activities up to the farmgate or the fishing port. This focus was chosen because many of the sustainability issues are concentrated in this area. However, the ISU recognises that production should be seen in the context of broader food systems, which encompass distribution, processing, retailing and consumption, and that changes to production may need to be part of wider and coherent changes to the whole food system, including consumer demand, food waste, international trade, economic development and land use change. The ISU approach provides a point of entry into a much more complex problem.

It is hoped that this report will stimulate useful dialogue, and perhaps act as a point of consensus for the many experts, practitioners and policymakers who realise that current agricultural and fisheries practices are in need of substantial reform. The ISU intends to convene others around specific themes outlined in this document, with the goal of generating consensus and catalysing action on some of the key challenges facing the global food system.

2 Introduction: a food system in crisis

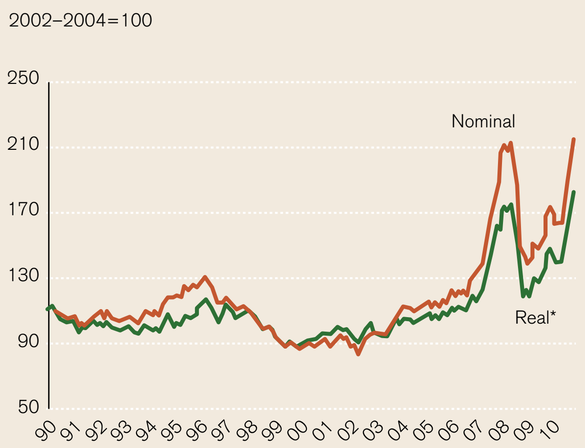
The world's food systems are failing. The symptoms are volatile prices, hunger and insecurity. The near-term causes are many, but underlying them are fundamental problems associated with poverty, the erosion of natural capital, energy and input scarcity, and climate volatility. Radical change is needed to ensure sustainable and resilient food supplies.

2.1 **The global food crisis**

The global food system is in crisis. One obvious manifestation of this crisis is the price volatility that has gripped markets in recent years. During 2007 and the first half of 2008 the price of staple crops such as maize, wheat and rice more than doubled. The Food Price Index of the UN's Food and Agriculture Organization, which tracks the prices of a basket of foods in local markets around the world, rose by almost 90% (see Figure 1). Prices fell by one-third over the following twelve months but during 2010 they rose sharply again. By early 2011 the UN's Food and Agriculture Organization (FAO) Food Price Index had reached its highest level since it began in 1990.[6]

The impact of rising and more volatile food prices has been immense, especially in poor countries and in those countries with weak governance structures or limited social protection. In developing countries, most people spend from 50% to 80% of their income on food, so rising prices have an immediate impact on wealth and nutrition.[7] During 2008 it is estimated that at least 110 million people were driven into poverty and 44 million more became malnourished.[8] The total number of people going hungry rose to 1 billion by 2009, more than one-seventh of the world's population and the highest number for 30 years. The number fell to 925 million in 2010 because of declining food prices and an improving economic environment, but with recent food price rises the number is increasing again[9] (see figure 2). Recent research indicates that an additional 1 billion people suffer from 'hidden hunger', lacking essential micronutrients such as vitamins and minerals in their diets.[10] This has dire consequences for the survival and growth of children, and for health and productivity across age groups.

Figure 1 – Food prices are rising and becoming more volatile



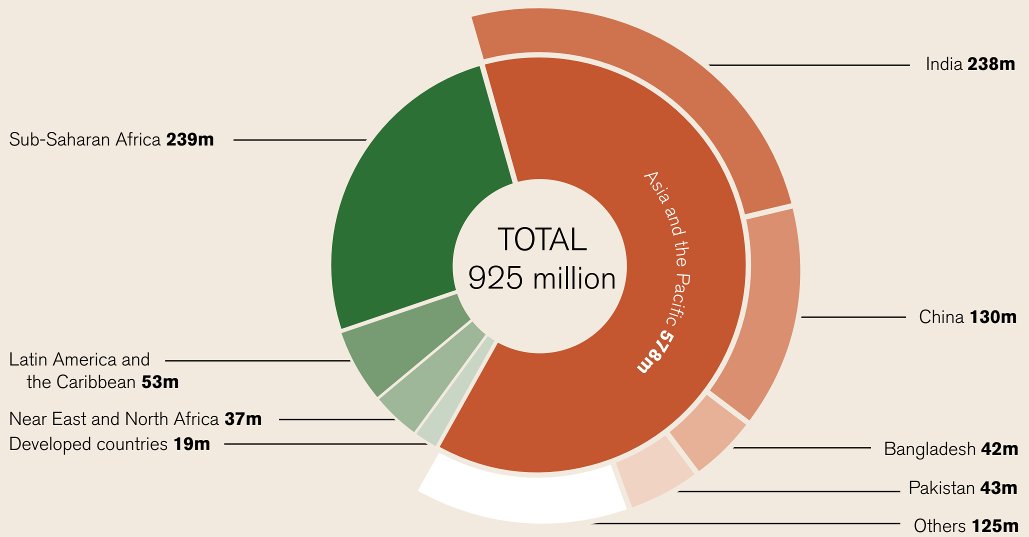
*The real price index is the nominal price index deflated by the World Bank Manufactures Unit Value Index (MUV)
Source: FAO Food Price Index

Rising and more volatile food prices have also led to political and economic disruption. Food riots or civil unrest broke out in many developing countries – Haiti, Ethiopia, Yemen, Mozambique, Morocco, Egypt and Mexico to name a few – and contributed to the overthrow of governments. Events on food markets have led to higher levels of inflation across the globe. For example, annual food inflation exceeded 15% per annum in India and 10% in China in early 2011, and is expected to approach 7% in Britain in 2011.[11] Food market volatility has also affected the fiscal position of those governments that subsidise domestic prices, as well as the trade balances of countries that rely heavily on food imports. Food price rises have benefited some farmers, but many of the poorest farmers in developing countries have been unable to take advantage because of weak linkages to markets.

The volatility in global food markets is not entirely unprecedented. During the early 1970s many food commodities experienced a doubling or tripling in price in a short period. But food is more heavily traded now than in the past: trade now represents about one-sixth of total

6 Blas, J. (2011) In Depth: The Global Food Crisis. *The Financial Times*
7 Evans, A. (2009) *Feeding the Nine Billion*. London, Chatham House
8 World Bank. (2008) *World Development Report 2008*. Washington, World Bank
9 FAO. (2010) FAOSTAT Database
10 Foresight. (2011) *The Future of Food and Farming: Challenges and Choices for Global Sustainability*. London, The Government Office for Science
11 Economist. (2011) The Consequences of Costly Nosh. *The Economist*, (January)

Figure 2 – Number of undernourished people in 2010, by region



Note: All figures are rounded
Source: Adapted from FAO data

production compared to one-ninth in the 1960s. Also, developing countries are more reliant on food imports than before: they imported 14% of their food between 2000 and 2004 compared to just 4% between 1970 and 1974.[12] Therefore, changes in global prices affect more people and more vulnerable people. The recent changes have come after almost three decades of generally stable and declining prices (in real terms), which has accentuated the dislocation. And, while some commentators during 2007 and 2008 confidently predicted a return to this trend of long-term price falls, the most recent research indicates that higher and more volatile prices are here to stay.[13]

2.2 The policy response

Encouragingly, food security is now at the top of the agenda for national and international policymakers. In response to the food crisis of 2007-2008, the UN Secretary-General established a High-Level Task Force on the Global Food Security Crisis. At the G8 meeting in L'Aquila in July 2009, leaders committed $22 billion in funding over three years for a new food security initiative, and at the G20 meeting in Pittsburgh the World Bank was called upon to set up the Global Agriculture and Food Security Programme. At the end of 2009, a World Food Summit hosted by the FAO in Rome agreed on the need to work towards a Global Partnership on Agriculture and Food Security and reformed the Committee on Food Security. The G20, under the presidency of France, has put the issue at the centre of planned meetings in 2011. These include the preparatory meetings for the 'Rio+20' summit in 2012 and the Conference of the Parties to the UN Framework Convention on Climate Change to be held in Durban, South Africa in December 2011.

A number of specific proposals have been put forward to address the volatility in global food markets. One area of consensus is that more needs to be done to improve the productivity of agriculture in developing countries. This will require a long-term programme of investment. But many of the proposals focus on mechanisms to reduce volatility or to mitigate its impacts on the most vulnerable. These include the following:

- **Information and Research:** creating early warning mechanisms, improving long-range weather forecasting, establishing a new International Food Agency or an Agricultural Market Information System
- **Trade facilitation:** agreeing codes of conduct on the use of export bans, establishing new mechanisms to assist importing countries to access global food markets, dismantling subsidies and tariffs that impede trade
- **Protecting the poor:** mobilising funds and food reserves to provide emergency food aid, or expanding social protection schemes in developing countries
- **Reserves and stocks:** creating much larger physical food reserves at international, regional or national levels to buffer temporary shortages
- **Financial instruments:** creating virtual reserves through futures markets, or increasing availability of risk and insurance instruments for farmers
- **Regulatory proposals:** limiting speculation in food markets by increasing transparency requirements or restricting use of futures market by speculators[14]

12 Anderson, K. (2010) Globalization's effects on world agricultural trade, 1960-2050. *Philosophical Transactions of the Royal Society*, 365 (1554)

13 IFPRI. (2010) Reflections on the global food crisis: How did it happen? How has it hurt? And how can we prevent the next one? Washington, IFPRI.; Evans, (2009); Foresight, (2011)

14 High Level Task Force on Food Security (HLTF). (2008) Comprehensive Framework for Action. New York, UN; HM Government (nd). The 2007/2008 Agricultural Price Spikes: Causes and Policy Implications; IFPRI, (2010); Zoellick, (2011); Foresight, (2011)

Many of these proposals could play a useful role in dampening market volatility and mitigating some of the worst effects of the food crisis in the short-term. However, on their own they will not be sufficient to build sustainable, equitable and resilient food systems for the future. This is because they mostly address the symptoms, rather than the causes, of the challenges facing the global food system.

2.3 **Multipliers and underlying causes**

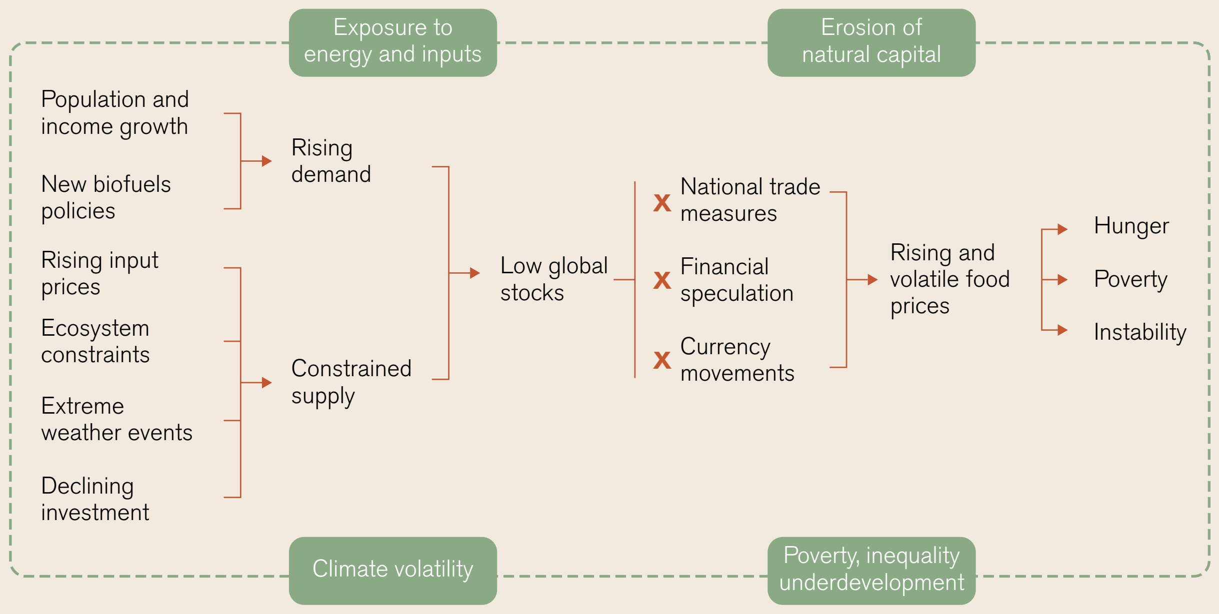
What has caused recent volatility and price rises in food markets? A swelling body of literature has examined this subject. There is general agreement that it is not possible to identify a single cause: it has been described as a 'concatenation of trends', the product of 'cumulative effects'.[15] Nevertheless, it is possible to separate proximate causes from ultimate causes and to identify a chain of cause and effect. The ISU believes that the food insecurity and price volatility of recent years are manifestations of much deeper issues which are only likely to intensify in coming decades.

Three economic factors have been identified as contributing to the volatility of food markets (figure 3). The first is national trade policy. Beginning in the second half of 2007, as prices rose, exporting countries such as Kazakhstan, Russia, Ukraine, Argentina, India and Vietnam sought to restrict the export of staple foods from their countries in a bid to protect domestic consumers. A survey of 81 developing countries by the FAO revealed that 25 banned food exports or increased taxes on exports. This deprived global markets of supplies.[16] A second cause may have been financial speculation. From 2006 investors who were seeking to diversify their portfolios away from stock markets and real estate poured money into agricultural commodities. (However, there is a vigorous debate about the extent to which such speculative flows magnified price rises rather than simply following them).[17] A third factor was the fall in the value of the United States dollar, which depreciated by 30% against other major currencies between 2002 and the middle of 2008. The majority of agricultural commodities are denominated in dollars, and the United States is a major exporter of these commodities, especially maize, wheat and soybeans. Falls in the dollar can cause demand for United States exports to increase and lead to a countervailing rise in commodity prices.[18]

Trade policies, financial speculation and currency fluctuations certainly accentuated the volatility of the past few years. But, alone, it is unlikely that they could produce these market movements. Instead, it is better to see them as multipliers acting on other factors.

One such factor has been identified as declining global food stocks.[19] Reserves of the three major grains (wheat, rice and maize) began to decline steeply from 2000, dropping from 100 days to just over 60 in 2004.[20] Global stocks have risen since the lows of 2007 but much of the increase has

Figure 3 – Causes of the global food crisis



Source: ISU analysis

15 Evans, (2009); HLTF, (2008)
16 IFPRI, (2010)
17 Foresight, (2011)
18 Piesse, J. & Thirtle, C. (2009) Three Bubbles and a Panic: An Explanatory Review of Recent Food Commodity Price Events. *Food Policy*, 34 (2), 119
19 Piesse & Thirtle, (2009)
20 Trostle, R. (2008) *Global Agricultural Supply and Demand: Factors Contributing to the Recent Increase in Food Commodity Prices.* Washington, USDA, Economic Research Service

Figure 4 – Global production and consumption of maize, wheat, rice, sorghum and barley

Source: PSD database, USDA

occurred in countries such as China and India, which have been unwilling to release stocks for sale on international markets. Low stocks, or unavailable stocks, make it more difficult to cover temporary shortfalls in production; instead, prices have to rise to ration demand. Government policies since 2000 undoubtedly contributed to the reduction of food reserves later in the decade. Yet, once more, it is better to see this factor as a magnifier of underlying causes rather than a major cause in itself. Ultimately, global stocks are a function of supply and demand. The run-down of stocks reflected deeper issues, namely increasing demand and constrained supply, which led production of major food staples to fall behind consumption for seven of the eight years from 2000 to 2008.

How has demand for food and the supply of food changed over the past decade? On the demand side, the world's population grows by 1.2% each year, down from a peak of 2% per year around 1970, but still considerable. Each day, there are an extra 219,000 mouths to feed, mostly in developing countries.[21] Rising incomes in developing countries, especially Asia, are also causing diets to change, with growing demand for meat, dairy products and vegetable oils. A newer factor in demand is biofuels policy. Large amounts of corn, sugar cane and vegetable oil are now diverted to produce fuel instead of food.

Rising demand would not be a problem if the supply of food was able to keep pace (figure 4). But this has not been the case. Agricultural yields, on a per hectare basis, grew by 2% per year between 1970 and 1990, but yield growth fell to just 1.1% per year between 1990 and 2007.[22] In certain regions, farming has faced serious constraints because of a lack of fertile land or fresh water, while in the seas many fish stocks have been over-exploited. Severe weather events, whether in Australia, Pakistan or Russia, have disrupted crop production. The cost of growing food has gone up, because of higher energy prices and the knock-on effect this has on agricultural inputs such as fertilisers. Finally, a more chronic problem has limited food supply over recent decades – a persistent decline in public investment in agriculture, in particular in developing countries.

When the layers of the onion are peeled away, the global food crisis can be seen as the product of multiple causes and effects. Price rises and market volatility have been accentuated by national trade policies, commodity speculation and currency rate movements, which multiply the impact of low global food stocks. These lower stocks were caused by the interaction of rising demand and constrained supply over a number of years.

Yet, underlying these interactions, it is possible to identify four trends which go a long way towards explaining recent price rises, price volatility and the impact this has had on millions around the world. These are:

(i) the exposure of modern food systems to rising energy and input costs;

(ii) the erosion of natural capital in the form of soils, water and other ecosystem services;

(iii) the vulnerability of food systems to extreme weather events and climate change; and

(iv) the persistence of poverty, inequality and underdevelopment in large parts of the world.

The following chapter will explore these risks in more detail and show how they have contributed to the current food crisis. It will also assess how they are likely to evolve over the coming decades.

Food aid being delivered in Kalsaka Village, Yatanga Province, Burkina Faso

21 Brown, L. (2011) The Great Food Crisis of 2011. *Foreign Policy*

22 Evans, (2009)

2.4 The need for change

There is a growing recognition of the need for radical reform of agriculture and fishery practices. For example, the Foresight 'Future of Food and Farming' initiative, a 2-year process sponsored by the UK Government involving hundreds of scientists from around the world, concluded that the global system is 'failing', that 'business as usual' is 'no longer a viable option' and that 'the case for urgent action in the global food system is now compelling'.[23] Many other initiatives have come to a similar conclusion.

Yet, many of the policy measures put forward in response to the recent food crisis address the symptoms rather than the deeper problems that lie beneath. They are designed to reduce market volatility or to ameliorate the worst consequences for the food insecure. Such measures can play a useful role in the short-term. But in order to build truly resilient food systems, any response must also include long-term measures to reduce the risks associated with energy dependence, the erosion of natural capital, climate change and rural poverty. This is especially important because, as the next chapter will explore, these risks are likely to intensify if we continue on our current path.

23 Foresight. (2011) *Synthesis Report C10: Volatility in Food Prices*. London, Government Office for Science

3 Risk and resilience

The global food system is vulnerable to risks associated with energy scarcity, the erosion of natural capital, climate change and poverty. These risks are likely to intensify in the future and to magnify one another. Strengthening resilience must be a top priority.

3.1 Food systems and risk

The recent crisis illustrates how vulnerable the global food system is to disruption. This is of great concern because the system can only tolerate a very low level of risk. Human society can survive without cars, computers and even electricity, but it cannot last long without food. Consequently, there is no point building a food system that gives high outputs for nine out of ten years but then collapses in one year due to internal stresses or external shocks. *De*-risking the world's food system must be a top priority.

This chapter explores four key factors that contributed to the current crisis and assesses what role they are likely to play in food production systems in the coming decades. They are:

- the exposure of modern food systems to rising energy and input costs;
- the erosion of natural capital, in the form of soils, water and other ecosystem services;
- the vulnerability of food systems to extreme weather events and climate change; and
- the persistence of poverty, inequality and underdevelopment

3.2 Exposure to energy and input prices

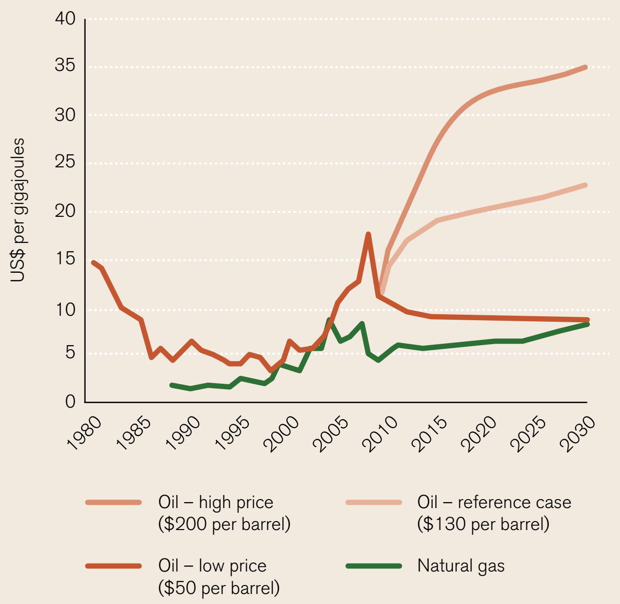
Modern food systems are heavily reliant on energy and mineral inputs, which makes them exposed to supply disruptions or price volatility in other commodity markets. Biofuels policies further link oil and food prices together.

Oil and gas

One of the most notable features of commodity markets in the past five years has been the strong correlation between food and oil prices. Industrialised farming systems are heavy consumers of fossil fuels, both directly in the form of fuel for farm machinery and indirectly in the form of the energy used to manufacture fertilisers, agro-chemicals and other inputs. For example, in US corn production, input costs (mostly energy-related) make up 37% of total production costs. Fishing fleets are also highly dependent on fossil fuel: fuel represents more than 50% of the operating costs of the Senegalese motorised canoe fleet.[24] Further energy is used for the transport and processing of food; in the European Union two-thirds of the energy consumed by the food supply chain is used for food processing and transport.

The world is approaching an 'energy crunch' as the production of oil peaks and then starts to decline. Recent years have seen marked rises in oil prices, and this has translated into higher operating costs for farmers: for example, prices for agricultural diesel in Australia rose by 95% between 2002 and 2008.[25] No-one knows how oil prices will change in the future. As figure 5 shows, the uncertainties are so great that the US Energy Information Administration uses three scenarios – ranging from $50 to $200 per barrel – when forecasting oil prices up to 2030.[26] But most observers expect volatility to increase. Oil price rises will be passed through to agriculture in the form of higher operating costs and then passed on to consumers in the form of higher food prices. Oil shocks are likely to become shocks for food systems too.

Figure 5 – Projected oil and gas ranges to 2030



Source: Woods *et al.* 2010

24 ISU case study research

25 ABARE. (2010) *Australian Commodity Statistics: Farm Inputs Data.* [Online] Available from: http://www.abare.gov.au/interactive/ACS_2005/htmlversion/htm/rural_com.html#farm [Accessed 20th February 2011]

26 Woods J et al. *Energy and the Food System.* Phil. Trans. R. Soc. B (2010); 365:2991-3006

Synthetic fertilisers, especially containing nitrogen, are an even bigger cost for industrialised farming systems. Between 2000 and 2008 the cost of nitrogen fertilisers increased fourfold.[27] This was driven by the soaring price of natural gas. Agriculture is especially reliant on natural gas because about 80% of all ammonia fertilisers are synthesised through the Haber Bosch process that uses the gas as a source of hydrogen as well as a primary fuel.[28] The production of ammonia accounts for only about 4% of natural gas consumption.[29] Therefore, the challenge is not one of absolute scarcity – the world can find natural gas to make fertilisers if it is essential – but rather one of price – fertiliser prices will track natural gas prices. Here, the recent development of new drilling techniques has released substantial quantities of so-called 'tight' or 'shale' gas. In the USA, as a result, the price of natural gas more than halved between 2008 and 2010.[30] If tight gas is found elsewhere, then the historic link between oil and gas prices may be broken. However, natural gas markets may still be subject to volatility. Europe, for example, relies on Russia for approximately one quarter of its gas, 80% of which is pumped through the Ukraine. As was witnessed in 2009 when Ukraine cut supplies, the price of gas in Europe can be just as volatile as the price of oil. Therefore, food systems may still be exposed to shocks from natural gas markets.[31]

Phosphates

Another finite resource crucial to modern agriculture is phosphate. Synthetic phosphate fertilisers are derived from mining phosphate rock, with 67% of production coming from three countries: China (35%); the USA (17%) and Morocco (15%). There are varying estimates of the extent of phosphate rock reserves: the US Geological Survey estimates there are 100 years of reserves that can be economically mined, whereas a more recent study by the International Fertiliser Development Centre puts the figure closer to 400 years. Estimating mineral reserves is complex as it depends on the cost efficiency of mining and extraction. New technologies and higher prices mean that lower grade ores become commercially exploitable. There are also opportunities to increase the capture and recycling of phosphorus from food, human and animal wastes.[32] As with ammonia, it is unlikely that phosphate fertilisers will 'run out' in the next hundred years. But the costs of production are likely to rise because of the need to turn to lower grade sources and because higher energy prices will feed through to the mining, extraction and transport of such a bulky commodity. Between 2000 and 2008 the price of phosphate increased fivefold. Prices have since come down but they remain well above the long-term average.

Biofuels

Further coupling of energy prices and food prices will occur because of the growth of biofuels and bio-energy. Over the last two decades, production and consumption of biofuels has been promoted because of national energy security and a desire to reduce greenhouse gas emissions. Between 1991 and 2006, the supply of biofuels increased by approximately 17% per year[33] (figure 6). A major acceleration occurred in the last five years when the United States mandated minimum ethanol blends in automotive fuel and provided generous subsidies for producers. In the United States, the proportion of corn used for ethanol rose from 7% in 2001 to 39% in 2010. Four out of every ten tonnes of corn grown in the USA now go to fuel vehicles.[34] The International Energy Agency (IEA) estimate that 33.3 million hectares, or about 2.2% of global cropland, is used to grow crops for bioenergy.[35] There is lively debate about the extent to which biofuels policy caused price spikes in recent years but most experts agree that it was a significant factor.[36]

Public subsidies and mandates guarantee that a certain proportion of these food crops will be diverted towards biofuels in coming years. But the volume of biofuels will also be determined by oil prices. Once crude oil prices reach $60 to $70 per barrel, ethanol and biodiesel become more competitive, which can lead to greater flows of food crops into their production.[37] First generation biofuels, currently

Ethanol biofuel factory, USA

27 Piesse & Thirtle, (2009)

28 Dawson, C. J. & Hilton, J. (2011) Fertiliser availability in a resource-limited world: production and recycling of nitrogen and phosphorous. *Food Policy*

29 Fixen, P. (2009) World Fertiliser Nutrient Reserves. *Better Crops with Plant Food*, 3

30 Economist. (2010) An unconventional glut. *The Economist*, March 11th 2010

31 Woods, J., Williams, A., Hughes, JK., Black, M. and Murphy, R. (2010) Energy and the food system. *Phil. Trans. R. Soc.* B 2010 365, 2991-3006

32 Dawson & Hilton, (2011)

33 IEA. (2010) *World Energy Outlook.* International Energy Agency

34 Wall Street Journal. (2011) Amber Waves of Ethanol. *Wall Street Journal*

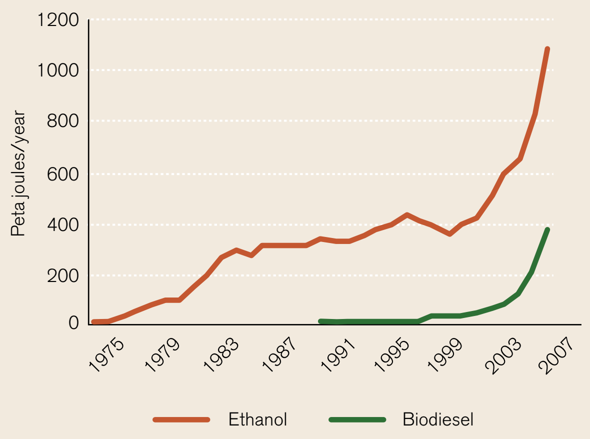
35 Fargione, J., Tillman, D., Hill, J., Polasky, S. & Hawthorne, P. (2008) Land Clearing and the Biofuel Carbon Debt. *Science*, 319 (5867)

36 Foresight, (2011). Synthesis Report

37 Schmidhuber, J. (2006) Impact of an increased biomass use on agricultural markets, prices and food security: A longer-term perspective. *Energy Security in Europe*; Climate Avenue. (2010) *The use of palm oil as biofuel and biodiesel.* Available from: http://www.climateavenue.com/en.biodiesel.palm.oil.htm

in widespread use, are derived from agricultural crops including maize, wheat, rapeseed, sugarcane, sugarbeet and palm oil. Attempts are being made to develop second generation biofuels derived from non-food feedstocks, such as miscanthus grasses, algae, jatropha, wood and agricultural waste. Electricity and heat can also be generated from diverse forms of biomass through combustion or anaerobic digestion. These alternatives would reduce the direct pressure on food markets, while creating new income opportunities for farmers and contributing to a low-carbon energy mix.[38] Yet, indirectly, second generation biofuels will still compete with agriculture for land, water and inputs, which will tend to preserve the link between food production and energy demand.

Figure 6 – Global production of liquid biofuels



Source: Brown 2008; FAO 2008; UNICA 2008

Modern food production systems are heavily reliant on non-renewable mined resources, such as oil, natural gas and phosphates. The higher and more volatile prices of recent years are expected to persist, as the more accessible reserves are depleted. There may be occasional shocks, if supplies falter because of conflict or trade disruptions. Disruptions to fuel and minerals markets will increasingly affect food systems and food security. Policymakers will need to take these linkages into account when assessing vulnerabilities and designing resilient food systems. And eventually the transition to renewable inputs will have to be made when these finite reserves begin to run out.

3.3 **Erosion of natural capital**

Agriculture and fisheries rely on natural ecosystems for their functioning. Yet, production systems are depleting natural resources at an unsustainable rate, approaching ecosystem limits, and, in some cases, coming close to ecological collapse.

Land and soils

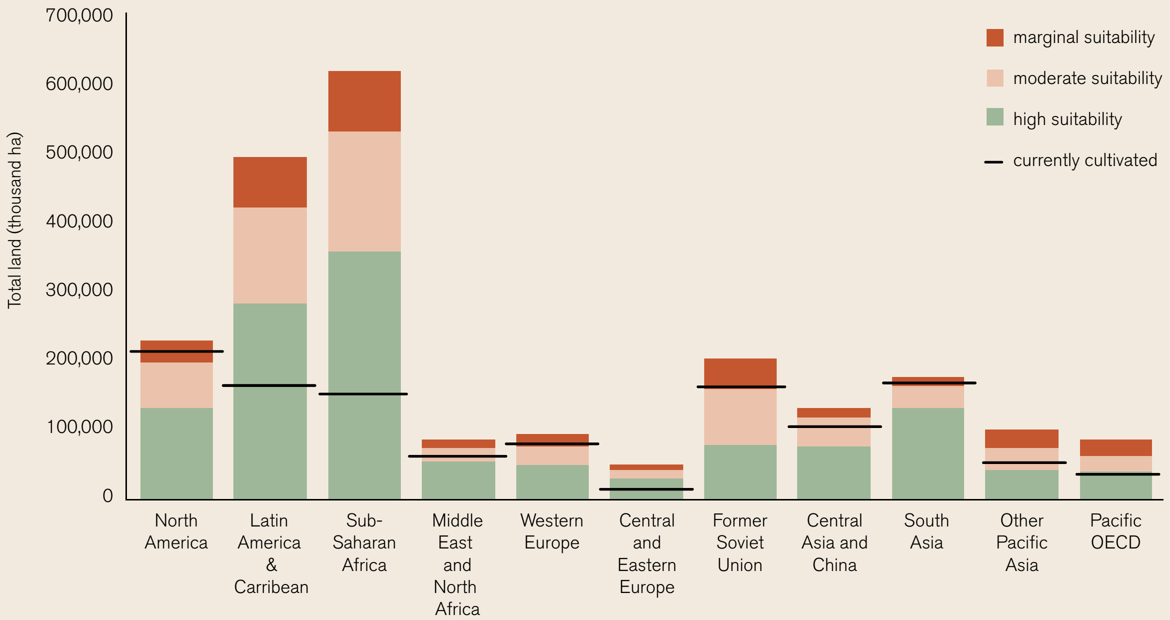
The productivity of an agricultural system depends on the amount and quality of land available to it. There is considerable debate about just how much uncultivated land is available for agricultural expansion.[39] Nevertheless, studies show that there is limited new land available in Asia, Western Europe or North America: for example, in Asia, nearly 95% of potential cropland is being utilised.[40] There appears to be significant amounts of suitable land available in Africa and South America but bringing it into production would require substantial investment in land preparation, infrastructure and human capital.[41] It may also involve deforestation, the destruction of grasslands and important wetlands, and the loss of biodiversity, which therefore involves trade-offs. As a result, the recent Foresight study commissioned by the UK Government concluded that 'sustainable intensification', rather than expansion onto new land, is the best way forward.[42]

Yet, agricultural land is, in fact, being lost every year. Infrastructure and urban development tend to swallow up some of the best arable land, as populations are concentrated in naturally fertile areas. For example, China lost more than 14.5 million hectares of arable land (an area 7 times the size of Wales) between 1979 and 1995 to urban development.[43] Recent research indicates that the expected increase of the global urban population from 2.9 billion people in 2000 to 6.4 billion in 2050 could swallow up 67 million hectares, or about 4% of the world's current cropland.[44]

Agricultural land is also lost through degradation. This can mean two things: on the one hand, the decline of soil fertility, for example through the depletion of nutrients, the loss of soil organic matter, the build-up of salts or toxic chemicals, or changes in soil structure and consistency; on the other hand, the loss of soil through erosion, either by wind or water. Agriculture is the chief cause of this degradation. Over-grazing can strip the land of vegetation and turn semi-arid areas into deserts; deforestation can rob the land of nutrients and protection from erosion; poor irrigation can lead to salinisation and acidification; inappropriate farming practices such as excessive tillage, over-use of agro-chemicals, or failure to restore nutrients can lead to a loss of soil fertility. The result can be a decline in yields or forced abandonment of the land. The major degrading areas are in Africa, Southern China, North-Central Australia and the pampas of South America, home to about 1-1.5 billion

38 WWF. (2011) *The energy report: 100% renewable energy by 2050.* Gland, WWF
39 Evans, (2009)
40 UNEP. (2008) *The Environmental Food Crisis: The environment's role in averting future food crises.* UNEP/GRID ARENDAL
41 Fischer et al. (2002) *Global Agro-ecological Assessment for Agriculture in the 21st Century: Methodology and Results.* IAASA
42 Foresight, (2011)
43 ICIMOD, 2008 http://www.icimod.org
44 UNEP. (2008) *The Environmental Food Crisis: The environment's role in averting future food crises.* UNEP/GRID ARENDAL

Figure 7 – Suitability and use of land for rainfed cereal production



Source: IIASA GAEZ study
Note: Assumes the most suitable land is cultivated first.

people.[45] There is no evidence that the rate of degradation is slowing. Indeed, with pressure on food supplies growing in some of the worst affected areas, it is likely that the problem will increase if current practices continue.[46]

Water

Agriculture has also put more and more pressure on scarce water resources. Irrigation is crucial to the world's food supply: only 17% of the world's land is irrigated but this land produces around 40% of the world's food, as yields tend to be two or three times higher than on rainfed land. As river systems have become fully exploited, pumping groundwater from aquifers has become increasingly important, especially in South and West Asia and northern China. In India, water tables are falling so much that well-drillers now have to use modified oil-drilling technology to find water, sometimes drilling a whole kilometre underground.[47]

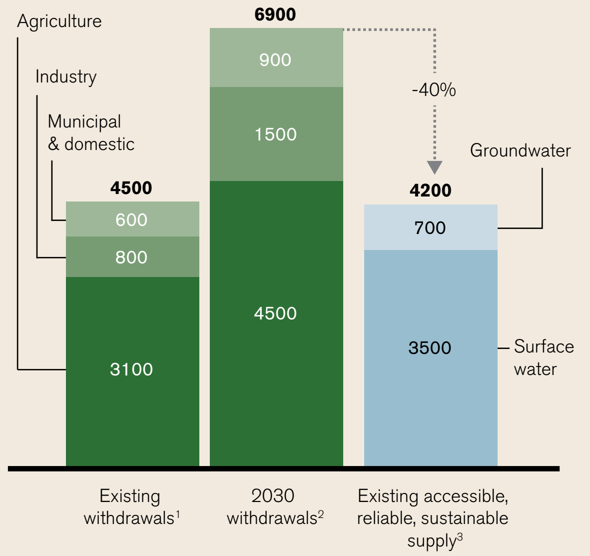
Saudi Arabia is a good example of how unsustainable water use is already leading to falls in food production. During the 1980s the pumping of water from underground aquifers allowed farmers to greatly increase domestic wheat production. The country achieved self-sufficiency and, by the early 1990s, became the world's sixth largest wheat exporter. But the water began to run out and as a result, the government decided to phase out the expensive subsidies that underpinned the irrigation programme. Wheat production halved between 2000 and 2008 and it will end entirely by 2016. As a result, Saudi Arabia is now a major wheat importer, buying in 3 million tonnes per year (about 2-3% of globally-traded wheat).[48]

Through deforestation, clearing of vegetation, draining of wetlands and over-tilling, agriculture can also have a negative impact on natural watershed regulation, increasing the risk of droughts and floods. This can damage local food production and can also have major impacts on downstream users, for example urban consumers or hydro-electric power facilities. Agriculture can also be a major cause of water pollution. In particular, nutrient run-off can lead to eutrophication of waterways: a study by the European Commission found that eutrophication accounted for almost 60% of all the environmental costs associated with the food supply chain in the European Union.[49]

Looking forward to 2030, research by McKinsey & Company for the Water Resources Group indicates that global water requirements will be 40% greater than the current sustainable supply, assuming current rates of economic growth (figure 8). This is because agricultural demand is expected to grow from 3,100 billion m3 per year to 4,500 billion m3 per year, while urban and industrial use will also grow strongly. The need to maintain environmental flow requirements to prevent the collapse of important riparian ecosystems will place additional limits on water

45 Bai et al. (2008) *Global assessment of land degradation and improvement: 1: identification by remote sensing*. Rome, FAO/ISRIC
46 UNEP, (2008)
47 Evans, (2009)
48 Rice, A. (2009) Is there such a thing as agro-imperialism? *The New York Times*; Lidstone, D. & George-Cosh, D. (2009) Saudi Food Adventure Needs Rethink. *The National*
49 IPTS, 2006. EU Environmental Impact of Products

Figure 8 – Global gap between existing sustainable supplies and projected 2030 water withdrawals



1 Based on 2010 agricultural production analyses from IFPRI
2 Based on GDP, population projections and agricultural production projections from IFPRI; considers no water productivity gains between 2005–2030
3 Existing supply which can be provided at 90% reliability, based on historical hydrology and infrastructure investments scheduled through 2010; net of environmental requirements
Source: Water Resources Group, 2009

availability. One-third of the world's population, mostly in developing countries, will live in basins where this deficit is larger than 50%.[50] This is in line with a forecast by the World Health Organization that water scarcity will affect over 1.8 billion people by 2025.[51] Water scarcity is one of the greatest threats to food production in some of the most populous parts of the world. In many of these areas this threat will be further magnified by climate change.

Pests and disease

The application of modern science to agriculture has brought huge advances in our ability to manage the threat of pests and diseases. However, despite these advances, 40% of the world's potential agricultural production is still lost to pests and disease, and agriculture remains vulnerable to outbreaks that threaten increasingly large proportions of global production.[52]

Certain trends may also undermine the natural resilience of agricultural systems. The first is homogenisation of crops and livestock and the erosion of genetic diversity. An ever greater proportion of the world's food supplies are produced from an increasingly narrow gene pool. A significant part of modern agriculture's success is due to selective breeding of high-yielding varieties, that may also contain natural resistance traits to pests and diseases. The use of genetic engineering may also provide advances in the future. But homogenisation increases vulnerability and increases the risk of widespread loss should outbreaks occur. The reduction of wheat varieties is a particular cause of concern. A new variant of wheat rust (Ug99) has spread from Africa to the Middle East and now threatens crops in densely populated South Asia, including India and Pakistan.[53]

A second set of risks is associated with the intensification of production systems. The use of nitrogen fertilisers for arable crops can increase susceptibility to fungal diseases and aphid attack. Farmers make heavy use of pesticides to control these threats, but widespread use over long periods, and inappropriate use, can increase selection pressures towards resistance. For example, the weed Amaranthus palmeri has developed widespread resistance to the herbicide Roundup in southern USA, especially affecting cotton.

The intensive raising of chicken, pigs and cattle – sometimes known as Confined Animal Feed Operations, or CAFOs – raises a different set of risks, as it can create the ideal environment for diseases to spread. This is a problem not only for livestock but for human health, as zoonotic diseases – those that pass from animals to humans – can emerge. It is estimated that about 75% of all diseases emerging during the last two decades have been zoonoses, including outbreaks such as Avian Flu and Swine Flu that have already cost governments billions of dollars. The widespread use of antibiotics in animal feed operations can also increase the selection pressure for antibiotic resistant pathogenic bacteria.[54]

Aquaculture is also susceptible to disease in a similar way as intensive livestock operations. In 2010, for the first time, over half of all fish produced for food was farmed rather

Workers disinfect a chicken farm in Guangdong Province, China as part of bird flu prevention and control measures.

50 Water Resources Group. (2009) *Charting our water future: Economic Frameworks to inform decision-making.* London, Water Resources Group
51 UNEP, (2008)
52 Pretty, J. (2006) *Agroecological approaches to agricultural development*
53 Singh et al. (2008) Will stem rust destroy the world's wheat crop? *Advances in Agronomy*, 98, 271-309.
54 WHO. (2004) *Report of the WHO/FAO/OIE joint consultation on emerging zoonotic diseases.* Geneva, WHO

than caught in the wild.[55] The outbreak of disease in a fish farm often leads to huge losses in production and can also spread to wild fish stocks. For example, the Chilean salmon farming industry, which had grown to become the world's second largest supplier, collapsed in 2007-08 due to the oubreak of the Infectious Salmon Anemia (ISA) virus.[56] Globally, cultivated shrimp production has levelled off since the early 1990s because of viral outbreaks.[57]

Biodiversity and ecosystem functionality

Soils, water and pest control – these are all ecosystem services that agriculture relies upon. The failure of any one can lead to a collapse in food production. It is also important to think of agriculture as part of broader, functioning ecosystems. These are not natural ecosystems; by definition, agriculture involves the manipulation of natural processes and the creation of man-made, agro-ecosystems. But the healthy functioning of these agro-ecosystems still relies on wild species and biodiversity.

This can apply at a continental level: significant changes to landscapes in one place can affect the functioning of agro-ecosystems elsewhere. One example is the interaction between the Amazon rainforest and food production in South America. The Amazon forest evaporates some eight trillion tonnes of water into the atmosphere each year. A large proportion of this is deflected south by the Andes, producing the rain that underpins a multi-billion agricultural complex in Brazil, Argentina and Uruguay. Some scientists believe that widespread clearing of the rainforest could produce a tipping point and lead to a dramatic die-off of the forest, changing rainfall patterns and causing more droughts thousands of miles away. 2005 brought a glimpse of what might happen if the rainforest disappeared: drought in the Amazon led to crop failures in southern Brazil and the Pampas region of Argentina.[58]

The loss of individual species, such as pollinators, could have a similar impact on agriculture. About 40-50% of food comes from crops that rely on wild pollinators or domestic honey bees. But over the latter half of the twentieth century populations of many pollinators have declined. For example, feral honey bee populations in many parts of the US have dropped by 90% in the past 50 years. Managed honey bee colonies have dropped by about two-thirds, in what has become known as Colony Collapse Disorder. Although the exact cause of decline is unknown, it is thought to stem from habitat fragmentation, the use of intensive modern agricultural techniques (monocultures and pesticides) and other factors including disease. One study estimates that the complete loss of such pollinators would reduce global food production by 3-8%.[59]

The loss of genetic diversity in agriculture reduces the genetic material available for future use by farmers and plant breeders. Seed banks such as the Global Seed Vault in Svalbard are an attempt to maintain this store of genetic material, but such a store cannot replace the continued natural evolution of species that occurs due to their cultivation under changing local conditions. Much of the yield increases or resistance to environmental constraints in modern crops is a result of genes from traditional varieties. The ability of crops and animals to adapt to future cropping systems and climate change will depend upon access to genetic variation.

The importance of functioning ecosystems is even more evident in the case of marine fisheries, which rely on natural upwellings of nutrients for the replenishment of stocks. Unfortunately, many of the world's fisheries are suffering such high fishing pressure that there is insufficient time for this natural replenishment of stocks. The latest FAO figures report that 32% of marine wild capture fisheries are over-exploited, depleted or recovering from depletion. An additional 53% of fisheries are being exploited at their maximum level, and there is a considerable risk that they will become over-exploited in the absence of management reforms. Some fisheries have already collapsed, for example the South American pilchard declined from 3.3 million tonnes in 1980 to almost zero in 2008.[60] Globally, the size of the total catch peaked in 1996 at an estimated 86 million tonnes and since then has levelled out at an annual production of approximately 80 million tonnes.[61] Wild marine fisheries have reached a production threshold. This is important as fisheries and aquaculture provide the main source of animal protein for over one billion people.[62]

The oceans are also home to a large proportion of the planet's biodiversity. The preservation of marine biodiversity is essential to ensure the continued productivity of the planet's fisheries.

Pollinating bumble bee, Denmark

55 FAO. (2011) Fish Consumption Reaches All Time High. [Online] Available from: http://www.fao.org/news/story/en/item/50260/icode/

56 UPI. (2010) Disease decimates salmon farms in Chile. Online from http://www.upi.com/Science_News/2010/08/17

57 Coelen, R. J. (1997) Viral diseases in aquaculture. *World Journal of Microbiology and Biotechnology*, 1

58 Werth, D. & Avisar, R. (2005) The local and global effects of African deforestation. Geophysical Research Letters, 32; Global Canopy Program (2007). *Forests first in the fight against climate change*

59 Aizen et al. (2009) How much does agriculture depend on pollinators? Lessons from long-term trends in crop production. *Annals of Botany*, 103, 1579-1588

60 FAO. (2010) *The State of World Fisheries and Aquaculture 2010.* Rome, FAO

61 FAO, (2010)

62 FAO. (2011) *Fish Consumption Reaches All Time High.* [Online] Available from: http://www.fao.org/news/story/en/item/50260/icode/ [Accessed 02/02/11]

Figure 9 – Reduction of diversity in fruits and vegetables, 1903 to 1983
(Varieties in US National Seed Storage Laboratory)

Vegetable	Taxonomic name	Number in 1903	Number in 1983	Loss (%)
Asparagus	Asparagus officinalis	46	1	97.8
Bean	Phaseolus vulgaris	578	32	94.5
Carrot	Daucus carota	287	21	92.7
Lettuce	Lactuca sativa	487	36	92.8
Onion	Allium cepa	357	21	94.1
Parsnip	Pastinaca sativa	75	5	93.3
Pea	Pisum sativum	408	25	93.9
Turnip	Brassica rapa	237	24	89.9

Source: Carry Flower, and Pat Mooney, *The Threatened Gene – Food, Politics, and the Loss of Genetic Diversity* (1990)

Removing any one species can have ramifications for the whole ecosystem by disrupting the natural balance between species, their competitors and their predators. Because so little is known about marine ecosystems and the complex relationships between species, it is difficult to estimate how many fish can be removed from each fishery without upsetting this delicate balance. The same principle applies to interactions between agriculture and natural ecosystems - the 'tipping points' at which ecosystem services break down and begin to impact on food production are poorly understood.[63]

3.4 Extreme weather events and climate change

One of the most visible causes of disruption to world food supplies over the past five years has been extreme weather events. In 2005, drought in Australia halved production while drought in Russia and Ukraine and a dry spring followed by harvest-time floods in Northern Europe damaged crops. World cereal production fell by 2.1%. Wheat harvests were then poor in 2006 and 2007 and markets expected a low harvest again in 2008.[64] In the end, world cereal production in 2008 and 2009 rose, but weather events again played a major role in 2010. Floods in Pakistan devastated the country's cotton and rice crops; Australian wheat producers were affected by rain; heatwaves and fires in Russia destroyed one-third of Russia's wheat crop and led to the imposition of export bans that threw markets into turmoil once again. In January 2011, Cyclone Yasi damaged sugar cane production in Australia, the world's third largest producer, sending sugar prices surging to a 30-year high.[65]

Since the development of agriculture, humans have enjoyed a relatively benign and stable climate – the last major swing was about 11,500 years ago when average surface temperatures rose abruptly by about 7 degrees Celsius. This is likely to change, as anthropogenic greenhouses gas emissions bring about a rapid warming of the planet. Even if steps are taken to stabilise greenhouse gases now, it is almost inevitable that temperatures will rise by at least 2 degrees by the end of the century. If emissions are not controlled – and little has been achieved so far – temperatures could rise by 5 to 6 degrees. Although it is difficult to link individual weather events and climate change, many experts believe that the extreme weather of recent years is an early sign of the more volatile climate that will be brought about by anthropogenic climate change.[66] 2010 was the second hottest year globally since records began in the 19th century – all of the ten warmest years have been since 1998.[67]

There have been many attempts to model the impact of rising temperatures on agricultural production, although considerable uncertainty remains. The latest assessment of the Intergovernmental Panel on Climate Change concluded that global productivity would increase between now and 2050, before declining thereafter as climate change intensified.[68] A recent study estimated that agricultural yields on currently cultivated lands would decrease overall by between 3% and 16% by the 2080s, assuming a 4.4°C rise in temperature[69] (Figure 10).

Yet, even these findings could be over-optimistic. The models assume that the negative impacts of higher temperatures and changing precipitation patterns will be partly offset by the CO_2 fertilisation effect (which enhances photosynthetic activity) but there is considerable debate over whether this benefit will materialise. Global averages disguise wide variations between regions. Scientists believe that the high

63 Millennium Ecosystem Assessment (2005). *Ecosystems and Human Well-being: Synthesis*. Island Press, Washington, DC

64 Foresight, (2011)

65 Bloomberg. (2011) *Cyclone hits australian sugar as global prices surge*. [Online] Available from: http://www.bloomberg.com/news/2011-02-02/cyclone-yasi-hits-australian-sugar-crops-price-advances-to-30-year-high.html [Accessed 15th February 2011]

66 Schiermeier, Q. (2011) Increased flood risk linked to global warming. *Nature*, 470 (316)

67 Reuters. (2011) *Factbox: 2010 second hottest year on record*. [Online] Available from: http://www.reuters.com/article/2011/01/20/us-climate-temperatures-factbox-idUSTRE70I46U20110120

68 IPCC. (2007) *The AR4 Synthesis Report*. Geneva, IPCC

69 Cline, W. (2007) *Global warming and agriculture: Impact estimates by country*. Washington, Center for Global Development

latitudes – places such as Northern Europe, Canada and some parts of Russia – will experience increased agricultural productivity but that low and mid-latitude regions will be negatively affected. This includes heavily populated and fast-growing regions such as Africa, the Middle East, South Asia and Southeast Asia. Small increases in temperature in these latitudes can have a great impact because agriculture in parts of these regions is already close to its biophysical limits. A study synthesising the major modelling efforts undertaken over the past two decades concludes that Africa faces 17-28% lower yields, and Latin America 13-24% lower yields. In India, the range of possibility is between -30% and -40%.[70]

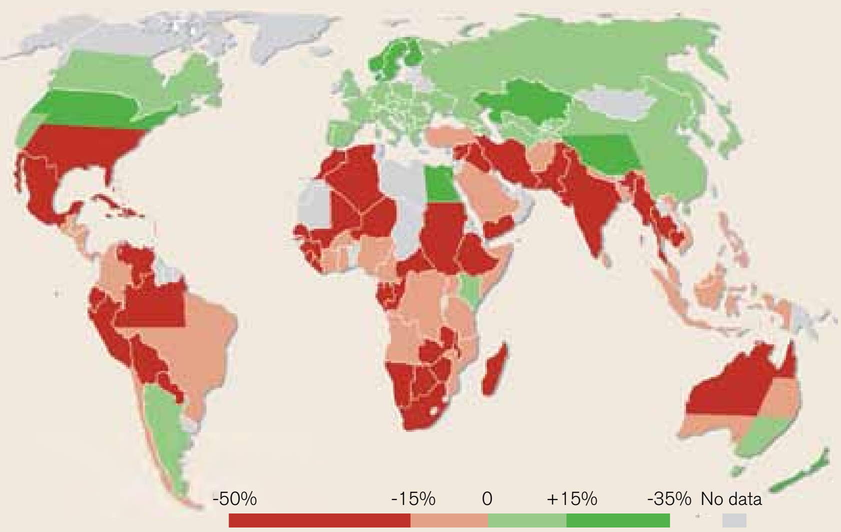
Most importantly, the current models do not take into account the impact of more extreme weather events, such as droughts, storms or floods. It is extremely difficult to predict when and where these might occur, but there is a general consensus that most regions of the world are likely to experience more extremes of temperature and precipitation. Changes in the frequency and severity of individual extreme weather events will have a much bigger impact on food production and food security than mean changes in climate.[71] Therefore, the weather events that disrupted global food markets in the past five years may be a sign of things to come.

Agriculture, the human activity that will be most seriously affected by climate change, is a major contributor to the problem. Agriculture is directly responsible for 13% of greenhouse gas emissions and, indirectly, it is largely responsible for another 17% of emissions associated with deforestation and land use change.[72] Yet, agriculture can also be part of the solution. Certain farming practices can help sequester carbon, drawing CO_2 from the atmosphere and storing it in soils and plants. The right land-use decisions can also help to preserve the world's remaining forests; huge stores of carbon which can also go on sequestering CO_2 from the atmosphere.

Climate change is just as much a threat to marine fisheries. Climate change and increased CO_2 assimilation in the oceans will result in increasing ocean acidification and disruption of thermohaline circulation and other processes. One of the most immediate impacts may be on coral reefs. While covering just 1.2% of the world's continental shelves, coral reefs are home to an estimated 1-3 million species, including more than a quarter of all marine fish species. Some 30 million people in coastal and island communities are reliant on reef-based resources as their primary means of food production, income and livelihood. Coral reefs also shield thousands of kilometres of coastline from wave erosion, and protect lagoons and mangroves, that are vital habitats for a range of commercial and non-commercial species.[73] It has been estimated that climate change could cause up to 80% of these coral reefs to bleach, with major knock-on implications for food security in these areas.

Ultimately climate change is likely to act as a multiplier of many of the other threats describes above. Areas that currently suffer from water stress are likely to get drier. For example, half of California's water comes from mountain snowpack; under climate projections 70-90% of this snow could disappear by the end of this century, with serious knock-on effects for Californian agriculture.[74] More violent

Figure 10 – Projected changes in agricultural productivity in 2080 due to climate change, incorporating the effects of carbon fertilisation



Source: Cline, 2007

70 Cline, (2007)
71 UNEP, (2008)
72 IPCC, (2007)
73 TEEB. (2010) *Mainstreaming the Economics of Nature: A Synthesis of the Approach, Conclusions, and Recommendations of TEEB.* UNEP
74 IPCC. (2007) *The AR4 Synthesis Report.* Geneva, IPCC

A partially dried up water source in Yingtan Province, China

flooding will increase soil erosion, while more frequent droughts will accelerate desertification in other areas. Changing temperatures will shift the prevalence of pests and diseases in unpredictable ways. Entire ecosystems may be transformed. Agriculture will need to adapt to long-term changes in temperature and precipitation and to increased weather volatility.

3.5 **Poverty, inequality and underdevelopment**

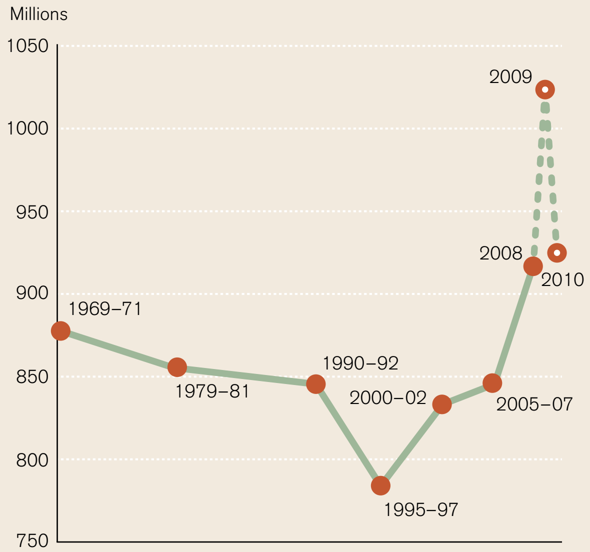
The increasing exposure of modern food production to energy and mineral prices, the degradation and depletion of environmental services, and extreme weather events and climate change are all placing strains on the world's food system. But the geographic imbalances between demand and supply, and the persistent poverty and inequality that exist in the world are what turn volatility on global markets into a crisis of survival for millions.

Mass hunger did not begin with the recent food crises. Declines in the number of malnourished people from the 1960s began to reverse in the late 1990s, and by 2000 there were already 825 million hungry. At the same time, over-consumption became a greater problem in industrialised countries and among the middle classes of emerging economies – it is estimated that 1 billion people are currently overweight and a further 475 million are obese.[75] For decades, in simple calorie terms, there has been plenty of food to feed the world. But it has been produced in the wrong place, much of it has been fed to animals to produce the meat and dairy products that high-income consumers demand, and much has been wasted.[76] Some societies have over-consumed; others have been too poor to capture a share of the global surplus.

One reason for these global imbalances is the low productivity of farming in many developing countries. At a macro level, over the past twenty years many regions experiencing the most rapid population growth and increased demand, especially in Africa, have not been able to increase agricultural output at a similar rate. At a micro-level, many farming households in developing countries are under-nourished because they cannot produce enough to feed themselves. 50% of the world's hungry are smallholder farmers, while another 20% are rural landless labourers and 10% are pastoralists, fishers or forest users. The majority of smallholder farmers are net buyers of food.[77] Low farm productivity means that food is scarce in rural areas, little surplus is produced for towns and these countries are forced to rely on food aid or food imports for survival. It is also a major cause of rural poverty. Three out of four poor people live in rural areas, 2.1 billion living on less than $2 a day and 880 million on less than $1 a day.[78]

Low productivity in many developing countries is not simply due to poor natural endowments: it is estimated that yields could be tripled or quadrupled using farming practices common elsewhere. There is an enormous 'yield gap' between the most and least productive parts of the world. One of the reasons cited for stagnating yields is the decline in investment in agriculture over the past three decades. The share of Official Development Assistance devoted to agriculture fell from 17% in the 1970s to just 5% in 2007. The share of total public spending on agriculture in developing countries fell from 11% in the 1980s to 5.5% in 2005.[79] There are many other reasons why agricultural

Figure 11 – Number of undernourished people in the world, 1969–71 to 2010



Note: Figures for 2009 and 2010 are estimated by FAO with input from the United States Department of Agriculture, Economic Research Service
Source: FAO

75 International Obesity Taskforce. (2010) *Obesity: the global epidemic.* [Online] Available from: http://www.iaso.org/iotf/obesity/obesitytheglobalepidemic/ [Accessed 15th January 2011]

76 UNEP, (2008)

77 Wegner,L & Zwart,G (2011) *Who will feed the world? The production challenge.* Oxfam

78 World Bank. (2008) *World Development Report 2008.* Washington, World Bank

79 FAO. (2009) *Foreign direct investment: win-win or land grab?* Rome, Food and Agriculture Organization

Farmers at work near the village Hagaz, Eritrea

©Stefan Boness / VISUM/Still Pictures

productivity has stagnated, such as weak institutions, corruption, poor infrastructure, dysfunctional markets, low levels of education, weak extension services, price controls, conflict and war. Addressing these issues is very complex, but the potential exists for developing countries to greatly increase their food production.

However, there are challenges too. Much of the degradation of soils, water and ecosystem functionality, together with the predicted negative impacts of climate change, is concentrated in developing countries which already struggle to feed themselves and where malnutrition is widespread. Moreover, most of the expected growth in world population, to 9.2 billion by 2050, will take place in these same areas. For example, the population of Africa, now one billion, is estimated to double by 2050. India is expected to become the most populous country in the world, growing from 1.2 billion to 1.75 billion people in the next forty years.[80] This population growth will place greater strain on already stretched natural resources. A revolution in food production will be needed in these areas to achieve sustainable food systems. Conversely, if such a revolution does not take place, the collapse of food systems in these regions would have ramifications for the rest of the world.

At the same time, the demand for food by the emerging middle classes is likely to continue to grow. The story is well-known. As people become wealthier they increase their consumption of meat, dairy products and vegetable oils. The consumption of meat and dairy products can have a knock-on effect on other food markets, as livestock are frequently raised on grain – using intensive farming methods it can take 2 kg, 6 kg or 13 kg respectively to produce just 1 kg of chicken, pork or beef.[81] Studies have predicted an increase in global per capita consumption of meat (kg/capita/annum) from 32 kg today to 52 kg by the middle of the century.[82] There will also be increased demand for non-food crops such as cotton or rubber, for high-value cash crops such as coffee and tea, and for biofuel feedstocks, which may cause land to be diverted from the production of staple crops. The growing purchasing power of middle income countries, together with the already expensive tastes of consumers in industrialised countries, are likely to place upward pressure on food prices on global markets, making it more difficult than in the past for low income countries to rely on cheap imports.

It is the task of the world trade system to even out the imbalances in demand and supply between regions. The proportion of food that is traded is growing, and it is predicted to grow further. Exposure to trade affects the economic incentives that food producers face and the way in which they manage natural resources. The theoretical models of many economists tend to show that economic efficiency and human welfare are optimised in a world of free trade, where all subsidies, tariffs and other barriers are removed. Yet, the reality of the last few years is that countries have increased trade restrictions in response to tightening food supplies, rather than lowering them. Efforts are underway to develop intergovernmental codes of conduct to limit such restrictions, as they magnify instability in global markets. But, when considering the resilience of a nation's food system, policymakers will have to consider the risk of trade disruptions and the possible impact of growing demand from developing countries on the availability and price of supply.

80 Population Reference Bureau. (2010) *PRB 2010 World Population Data Sheet*. [Online] Available from: www.prb.org/datafinder

81 Pimental, M. & Pimental, D. (2003) Sustainability of meat-based and plant-based diets and the environment. *The American Journal of Clinical Nutrition*, 78 (3)

82 FAO. (2009) Rome, Food and Agriculture Organization

3.6 **Inter-related risks**

Whilst food systems are vulnerable to individual risks, often these risks combine and reinforce one another. Similarly, responses that reduce one risk or stress can inadvertently magnify other potential stresses. Food security, energy policy, water availability, environmental degradation, political stability and national security are all linked and must be viewed in an integrated manner.

Environmental degradation and rural poverty often fuel each other. Because of a desperate need for food or income, poor farmers, for example, may deplete soil nutrients, cultivate unsuitable marginal land or clear essential forest in a way that is ultimately unsustainable. They may lack the capital to invest in better practices. Fishers may over-exploit fish stocks for the same reasons. On the other hand, poor people tend to rely more heavily on ecosystem services for the provision of food, water and energy, because they cannot afford to purchase manufactured inputs, technologies, fuels and other goods. They are also more vulnerable to failures in ecosystem services – for example, bad weather events – because they lack savings or risk mitigation instruments such as insurance. The poverty-environment nexus can quickly become a vicious cycle.[83] Rural poverty has many other causes too – weak institutions, low skills, poor infrastructure, dysfunctional markets, limited access to capital – but in many parts of the world breaking this cycle will be critical to a more prosperous future.

Pakistan is an example of a country facing multiple, reinforcing stresses - and straining under the pressure. Its population is growing rapidly and it will have 60 more million mouths to feed by 2025, but it faces significant ecosystem constraints in the form of limited land and water and a variable climate, which is predicted to worsen with global warming. Its agricultural productivity has failed to keep up, making the country more reliant on international markets and weakening its trade balance. At the same time, it suffers from a serious energy deficit, which has forced many people to clear forests to obtain fuel, thus increasing environmental degradation. Because of an expensive subsidy programme, the high costs of energy and fertilisers, mostly imported, have placed a huge strain on the government budget in recent years. Yet, 28% of the population are suffering from severe food insecurity, child malnutrition levels are among the highest in the world and food price inflation (which reached 20% in 2011) has led to riots in the street. The country is in the grips of a protracted food, energy and security crisis.[84]

Haiti also provides a stark example of a country caught in a vicious cycle of environmental degradation, poverty, and agricultural stagnation. Rapid population growth and demand for energy has led to deforestation, as trees have been cleared for fuel-wood or charcoal. The country now has just 2% forest cover. This has led to massive soil erosion: approximately 15,000 hectares of cultivated land are lost to erosion each year. The degradation of natural resources is one of the reasons farmers struggle to produce enough food for subsistence needs. Other factors are poor access to credit, lack of infrastructure, low educational levels, limited access to inputs, and a lack of social capital. In response, more and more farmers have turned to fishing. However, the use of finer nets means that smaller, juvenile fish are getting caught so fish stocks are rapidly depleting. In rural areas, which are home to half of the population, two thirds are extremely poor, while per capita incomes are one-third of those in urban areas. The country imports 60% of its food needs. Further, as has recently been so tragically demonstrated, the country is vulnerable to natural disasters such as earthquakes and hurricanes. Climate change is likely to exacerbate the intensity of hurricanes, and their impact is already magnified by the lack of forest cover, which leads to devastating flooding and mud slides - further reducing agricultural productivity.[85]

While the impact of these inter-related risks is most apparent in developing countries, developed countries also have to grapple with the economic consequences of environmental degradation. For example, Australia has recently experienced an environmental and economic crisis in the Murray Darling River Basin. Here, intensive agricultural production has been practiced since the 1880s, supporting a buoyant dairy and horticulture industry. But the clearing of more than 70% of the native vegetation to open up farmland and the subsequent introduction of irrigation have substantially altered the hydrological balance of the catchment, bringing deep salt deposits to the surface and affecting agricultural production, ecological functioning and infrastructure. As a result, the Australian Government has been forced to implement a basin-wide management plan which aims to restrict groundwater extraction for irrigation and attempts

Hume Reservoir with low water levels (12%) from the drought in 2008 in Albury, New South Wales, Australia. In the background are the Snowy Mountains and the headwaters of the Murray River. From the Hume Dam the Murray River will travel several hundred kilometers to its mouth on the coast of South Australia in Adelaide. Along the way it will be used by irrigating farmers. The Murray-Darling Basin of Australia has been plagued with severe drought since the late 1990's.

83 UNEP. (2011) *Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication*. www.unep.org/greeneconomy, UNEP

84 Stevens, D. (2011) Running out of everything: how scarcity drives crisis in Pakistan. *World Politics Review*, 3 May 2011

85 http://www.ruralpovertyportal.org/web/guest/country/home/tags/haiti; UNEP 'Food for the Poor'; http://www1.american.edu/TED/haitirice.htm#r5°

Figure 12 – UNEP estimates of impacts on food production by 2050

	Possible loss of cropland	Possible reduction in yields
Biofuels demand	-2% to -8%	
Demand for other non-food crops	-2.5% to -3.5%	
Urban build-up	-2.5% to -4.5%	
Land degradation	-1.5% to -2.5%	-1% to -8%
Water scarcity		-1.7% to -12%
Climate change*		-1% to -1.5%
Invasive species		-2% to -6%

Source: UNEP, 2008
* Does not include possible impacts of more extreme weather events or glacial melt

to restore environmental flows. Implementing a water rights system and then agreeing to buy back sufficient entitlements to restore flows to the prescribed level has already cost the federal government in excess of AU$3.1bn.[86]

These examples illustrate the importance of taking an integrated approach to food security. For too long, there have been two separate debates about the future of the global food system, one focusing on sustainability and the environment, the other on food security and hunger. The events of the past five years, and the risks that loom on the horizon, show that these cannot be separated. Sustainability and food security are two sides of the same coin. One is not possible without the other. A truly resilient food system will encompass both.

3.7 What resilience means

The concept of 'resilience' is beginning to receive more attention in academic and policy-making circles.[87] The ISU uses the following definition: resilience is the ability of a system to repel, absorb or adapt to disturbances while still retaining the same basic functions. It is useful to consider resilience of what: in this case, it is the ability of a food system to deliver a combination of economic, environmental and social goals. The other part of the equation is resilience to what: this can include sudden shocks and also more gradual changes, both coming from outside the system (exogenous) and generated by the unsustainable behaviour of the system itself (endogenous).

Resilience must operate at multiple scales, from the farm or fishing boat, to the village, watershed, region, nation or global trading system – at each level complexity increases. There may be critical thresholds or 'tipping points' which, when crossed, will severely disrupt the functioning of a system – resilience can be represented by the distance between a system state and a critical threshold. It is rarely simple to predict these thresholds in advance. This is due to the non-linear and multi-scale dynamics of social-ecological systems, the potential for sudden changes, the sensitivity to external perturbations and the reflexivity of human actions. As we have seen, risk drivers can also interact and reinforce one another. This means that solutions that address individual problems may be successful in the short-term but may also set in motion feedbacks and interactions among different parts of a system that have negative impacts. As a result, there is a need to manage for general resilience, as well as resilience to specific stresses.

Because of these complexities, adaptive capacity is key. If a system is too rigid, it can lead to pathological traps, for example, a food system that is stuck with low productivity and poverty. Sometimes change and reorganisation will be needed to improve the functioning of a system. If the external environment changes, a system may also need to go through a complete structural change in order to preserve its original social, environmental and economic functions. Food systems that are diverse, modular and flexible are more likely to have the adaptive capacity that will be needed to overcome the challenges of the coming decades. A focus on resilience broadens attention from growth and efficiency to risk, recovery and flexibility.

Although it is difficult to measure resilience, it is clear that it has an economic value. This can perhaps be best seen by looking at the costs of the current food crisis - higher food prices, increased subsidy bills, widespread malnutrition and political instability have cost society billions. This could be termed the cost of irresilience. The economic value of resilience is the ability of the global food system to maintain its functionality in the face of risks and shocks. This may have some upfront costs and may even mean accepting a lower level of economic output year-to-year. But if it mitigates risk it may be worthwhile. Insurance provides a good analogy: it makes sense to pay a regular premium if this removes the risk of catastrophic loss. Similarly, policymakers should consider what sort of premium might be needed to 'de-risk' the global food system.

86 Jeffery Connor, Mac Kirby, Kurt Schwabe, Anna Lukasiewicz and David Kaczan, (2008) *Impacts of reduced water availability on lower Murray irrigation, Australia.* CSIRO; http://www.ruralfutures.une.edu.au/downloads/WaterTrade_311.pdf
87 See, for example, the Resilience Alliance. http://www.resalliance.org

4 The true cost of food

Case studies commissioned by the ISU indicate that the market price of food does not reflect the true costs of its production, once subsidies and environmental damage are taken into account. Most of the systems studied were also vulnerable to risks and shocks. Economic frameworks need to be changed to encourage more beneficial and resilient alternatives.

4.1 Case study research

The previous chapter analysed the risks facing the global food system both now and in the future. It made the case that the system is vulnerable and lacking in resilience. But food production systems are so varied - across geographies and food types - that there is a limit to how much useful analysis can be done at a global, macro level. It is necessary to draw the boundaries more tightly. As a result, the ISU commissioned an external consulting firm to conduct studies on particular agriculture and fishery production systems around the world.

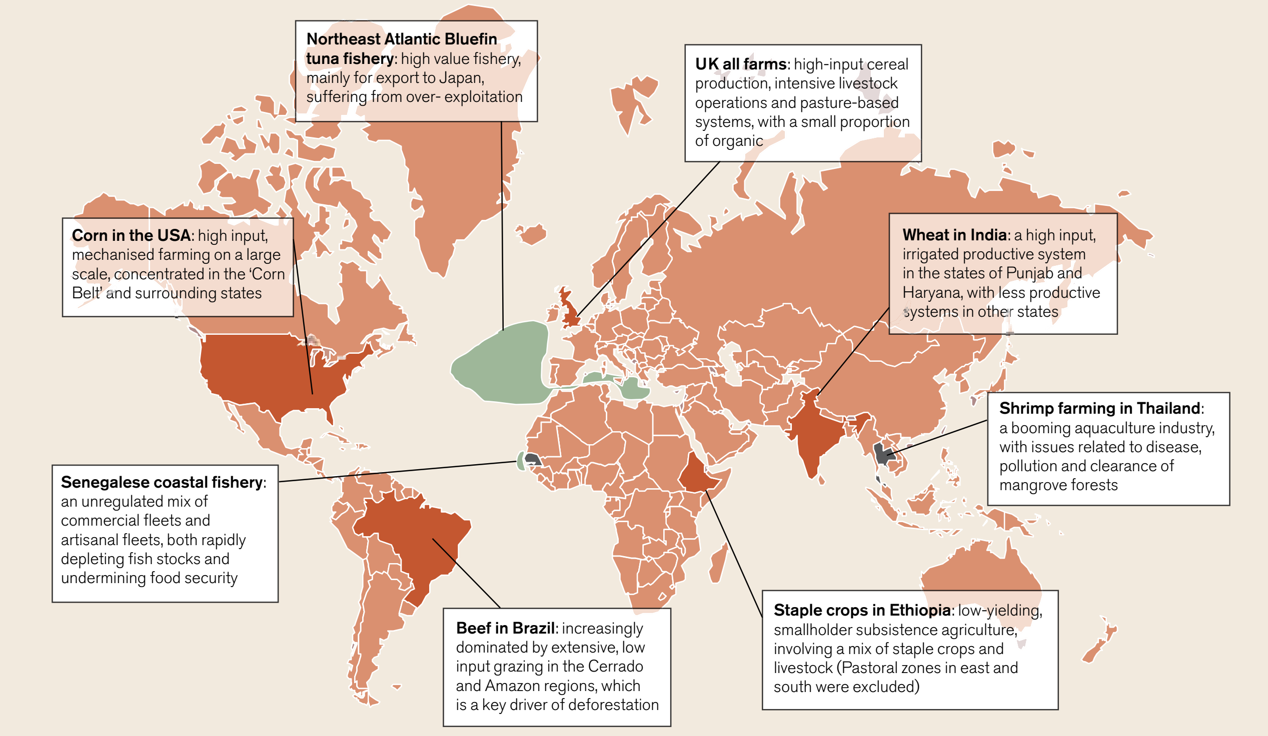
Five agriculture case studies, two fishery case studies and one aquaculture case study were selected: beef production in Brazil, corn (maize) in the USA, staple crops in Ethiopia, wheat in India, an 'average' farm in the UK, shrimp farming in Thailand, Bluefin tuna fisheries in the Northeast Atlantic and the Senegalese coastal fishery. These systems were selected based on the contribution they make to food production, their ability to illustrate different levels of technology and capitalisation, and the availability of data. They reflect a broad range of industrialised, middle income and less developed countries.

The primary goal of this case study research was to estimate the true costs and benefits of these systems by placing a value on public subsidies and environmental impacts, while also exploring some of the broader social impacts. A second goal was to better understand the vulnerability of each system to some of the risks outlined in the previous chapter. It could be argued that a higher level of risk in a system is acceptable if it produces a very high level of current social, economic and environmental benefits. As will be seen, these benefits were often not apparent.

4.2 Overview of methodology

Agriculture systems and fisheries are multi-functional. Their primary goal is to produce food for human consumption. But they must do this in a way that makes efficient use of

Figure 13 – Case studies commissioned by the ISU



economic resources, that minimises environmental pollution or the depletion of natural capital, and that contributes to social welfare. Food production systems must also be capable of delivering these goals well into the future and be resistant to shocks. The ISU's researchers developed a methodology that could assess the performance of food systems against these multiple dimensions. The methodology's four key steps are summarised below. (A more detailed description can be found in Annex A of this document.)

The first step was to value the **economic productivity** of the system. This involved calculating the output value of the food produced at the farmgate (or wharf), based on a five-year rolling average. The costs of production were then subtracted to give the private profit (or loss) generated by the system – this was the return to the food producer over the period in question. Finally, public subsidies and taxes as applied to the system were subtracted to reveal the full economic profit (or loss) for society of each system.

The second step was to value the **environmental impacts** of the production systems. These included both classic externalities – impacts outside the production system itself – and the depletion of natural resources that the production system relied upon. The goal of the research was to place a monetary value on these impacts, in US dollars, wherever possible. These environmental impacts included the following:

- **Greenhouse gas emissions**. Emissions from agriculture and fisheries were captured by life cycle analysis, which included emissions associated with the manufacture of inputs (such as fertilisers), the production of crops and livestock, the use of fuel in machinery, and land use change (such as deforestation or mangrove clearing). An attempt was made to calculate total emissions in tonnes of CO_2 equivalent (CO_2e), which was hard enough. Even more difficult was placing a dollar value on these emissions. For the purpose of the analysis, and recognising that there is much debate on the appropriate figure, the researchers assumed a social 'cost of carbon' of $29 per tonne of CO_2e.[88]
- **Air and water pollution**. Agriculture and aquaculture can add harmful chemicals, particulate matter and smoke to the air. This impact was calculated on the basis of the cost of this pollution to human health. The cost of water pollution included the cost of cleaning contaminated drinking water, the potential health impacts from water pollution and the economic loss to aquaculture and fisheries caused by pollution.
- **Soil degradation**. Agriculture can cause soil erosion and loss of soil fertility. The impacts were assessed in terms of the economic value of the output lost through this degradation.
- **Water depletion**. The cost of depletion of non-renewable water reserves (such as aquifers) in agriculture was calculated as the output foregone because of this depletion.
- **Biodiversity**. Although biodiversity is critical to ecosystem functionality, there is little consensus on how to value it in practical terms. This methodology used proxies where data has been found to exist. In one case, this meant the value placed on biological prospecting – i.e., the right to develop products from the genetic diversity found on a particular piece of land. In other cases, the value of specific ecosystem services such as pollination by wild insects was used.

The third step was to assess the **social impact** of food systems. This is a broad category and one that is not amenable to simple dollar values. It is a matter of qualitative analysis. The normative values can depend on political preferences. Nevertheless, an attempt was made to understand how a food system performed on certain dimensions. This included the contribution it made to food security by producing food surpluses; the impact on producer livelihoods; and the safety of working conditions. The ISU recognises that a full evaluation of social impacts would need to take into account broader issues.

The fourth step was to assess the **vulnerability** or **resilience** of the food system to risks and shocks. A thorough understanding of resilience would require scenario planning and sensitivity analysis across a number of dimensions, something which was beyond the scope of this research effort. Instead, the researchers looked at the

FIGURE 14

Limitations of the research

The ISU recognises the limitations of this research. The results are only as good as the data that could be found within existing scientific or economic literature. In all cases, local data was sought for the indicators, but where such data did not exist, proxies and extrapolations were used to derive estimates – there may be considerable error in these estimates. There were also certain environmental impacts that the methodology did not attempt to value. This included the value of water regulation services provided by landscapes, for example flooding control. No attempt was made to value the depletion of finite resources such as fossil fuels or phosphates. For the wild fisheries case studies, it was not possible to estimate any values for air pollution, water pollution or biodiversity loss. Economic data is based on averages of five year periods between 2002 and 2009, and therefore does not fully reflect recent price rises.

The approach taken was purposefully narrow. The focus was on production, i.e. the economics and impacts up to the farm-gate or the fishing port, and it excluded downstream activities such as trading, processing, distribution and retailing. The case studies focused on activity within individual countries and did not attempt to estimate the implications for trade or land use change in other parts of the world. The analysis was primarily static, rather than dynamic, and did not attempt to model how the parameters of these systems may change over time, for example. All these factors would need to be part of a comprehensive food systems analysis.

88 Tol, Richard S. J. (2009) The economic effects of climate change. *Journal of Economic Perspectives*, 23 (2)

Figure 15 – Economic productivity of food systems (US$)

Case study	USA corn	UK all farms (per hectare)	Brazil beef	India wheat	Ethiopia smallholder agriculture**	NE Atlantic Bluefin tuna	Thailand shrimp farming	Senegal coastal fishery
Revenues	36.6bn	1728	22.2bn	12.9bn	2.2bn	715m	1452m	160m
Costs	-36.3bn	-1435	-26.5bn*	-11.5bn	-2.4bn	645m	-1268m	165m
Private profit or loss	0.3bn	293	-4.3bn	1.4bn	-2.0bn	70m	184m	-5m
Subsidies	-6.3bn	-316	-0.5bn	-2.5bn	0	-120m	-125m	70m
Social profit or loss	-6.0bn	-23	-4.8bn	-1.1bn	-0.2bn	-50m	61m	-75m

Source: ISU case study research
* Includes an implied land rent which many ranchers may not pay, as land is often cleared and occupied illegally, rent-free
** Case study added off-farm income earned by farmers and subtracted the value of food consumed for subsistence

exposure of the food system to a smaller number of risks – volatile energy and input prices, land degradation, water scarcity, pests and diseases, and climate change.

This methodology was applied to current production systems to understand the full costs and benefits of 'business as usual'. Data was drawn from existing literature on these case study systems, where this could be found. In some cases, where there were gaps, figures were extrapolated from other countries or systems. The ISU recognises that there are many limitations to this research – see figure 14 for more details. The numbers should be regarded as rough estimates based on the best data available. In many cases, the quality of the data was poor. Nevertheless, it is hoped that the results of this research can provide a useful insight into the costs and benefits of key parts of food value chains.

4.3 How current food systems perform[89]

Although there are marked differences between the case studies, some common themes emerged.

Economic productivity

It is striking that across almost all of the food production systems, during the periods studied (five-year periods between 2002 and 2009), farmers and fishers struggled to make a profit within the prevailing economic framework. This applied to the 350,000 US corn farmers, who made industry-wide profits of just $300 million each year on revenues of almost $37 billion. It applied to the millions of Indian wheat farmers outside of the more developed states of Punjab and Haryana who made profits of around $200 million on revenues of $8.5 billion. It is similar for Senegalese fishers who made a loss of $5 million on sales of $160 million. The low private profits – and in some cases losses – reflect the fact that labour and assets, such as land and boats, often did not entail cash costs. Family labour and assets effectively subsidised production. In some cases, such as Brazil ranching, illegally cleared land was acquired for free.

Of course, these sector-wide figures disguise significant variation between producers. The large-scale or more efficient farmers and fishers made greater profits, while others may have been losing more. But the tightness of margins during the periods studied (generally before the large increases in food prices) may indicate that prices were then too low to stimulate the increased production needed to satisfy rising global demand – farming and fishing have not been very profitable activities. The low margins also help explain why producers were eroding natural capital and disregarding environmental externalities. Struggling for survival, they often did not have the luxury to think of long-term issues or broader public goods.

When public subsidies are taken into account, the total economic outcome for society looks even worse. In the US, the corn industry received over $6 billion of public subsidies per year during 2004-2008.[90] Indian wheat farmers received $2.5 billion per year during the same period.[91] UK farmers received about 18% of their revenues in the form of subsidies between 2005 and 2009.[92] Large subsidies were also made available to fishing fleets – in Senegal they accounted for 44% of the fishing industry's revenues. Across the eight case studies, public subsidies amounted, on average, to 18% of the value of the food produced. In only two countries – Brazil and Ethiopia – did farmers receive little or no subsidies. In every other case, the subtraction of public subsidies turned private profits into large social losses, or turned small private losses into much bigger social losses.

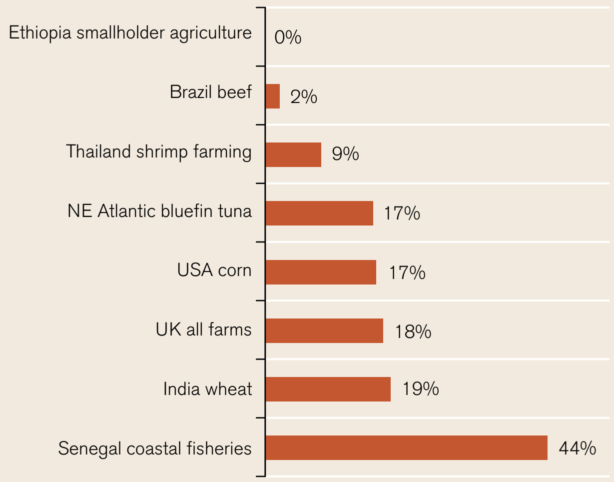
Environmental costs

So far, the figures only reflect the 'simple' economics of the food production systems, the sort of numbers that turn

89 Unless otherwise noted, please refer to Annexes A & B for further information
90 USDA NASS. (2010) *Data and Statistics*. [Online] Available from: http://www.nass.usda.gov
91 Ministry of Agriculture. (2010) Department of Agriculture and Cooperation: Statistics at a Glance. [Online] Available from: http://agricoop.nic.in/Agristatistics.htm
92 Farm Business Survey. (2010) *Region Reports: England*. [Online] Available from: http://www.farmbusinesssurvey.co.uk/regional/ [Accessed 15th November 2010]

up in national accounts or GDP calculations. When the environmental costs are taken into account, the 'true' social costs grow substantially. All the systems studied produced substantial environmental impacts.

Figure 16 – Public subsidies as percentage of producer revenues



Source: ISU case study research
Note: based on averages over five-year periods between 2002 and 2009

Greenhouse gases

One consistent feature across all the case studies was the production of greenhouse gases, either directly through production activities or indirectly through land clearing or land use change. When a social cost of $29 per tonne of CO_2e is assumed (recognising that there is no 'right' figure for this), the value of this impact can be very large (although it should also be recognised that this is a global social cost rather than a local or national cost, like some of the other environmental impacts).

This is most prominent in the case of Brazilian beef production, which is estimated to have been responsible for the emission of between 470 million and 580 million tonnes of CO_2e per year between 2005 and 2009. This represented a cost of $13.7 billion to $16.9 billion, which is over 60% of the value of all the beef produced per year. A little less than half of these emissions comes from the methane produced in the digestive tracts of cattle. The remainder is associated with the clearing of forest. Deforestation in these regions is complex and there are many factors involved, but one of the main drivers over the past decade has been cattle ranching.[93] It should be noted that deforestation rates in Brazil have declined since the period of the case study, due to concerted government action, so greenhouse gas emissions associated with cattle production are now almost certainly lower than these historical figures.

Intensive shrimp farming in Thailand may produce greenhouse gas emissions with a global cost equal to 16% of revenues, through the use of fuel for water pumping and the clearing of carbon-rich mangrove forests on the coast. Fishing fleets are large consumers of diesel fuel, which is why Senegalese coastal fishing was estimated to produce greenhouse gas emissions with a cost of $24 million per year, or 15% of the value of the fish caught. Finally, there were costly emissions associated with intensive, high-input cropping systems in the UK and USA, not least because of the manufacture of fertilisers, but this was partly offset by the high productivity of these systems – per tonne of food produced, emissions were lower than in some other forms of production.

Air and water pollution

Air and water pollution represented significant impacts in some regions. In Indian wheat production, for example, air pollution stems from the manufacture of inputs and agrochemicals, the use of diesel pumps for irrigation and the use of tractors and other farm machinery. Because of the density of the population, the researchers estimated that the health impacts would cost $2.1 billion to $4.2 billion if treated.

Water pollution is a major problem in US corn production because of high rates of fertiliser and chemical run-off and soil erosion. Mitigating the impacts of water contamination and sedimentation would, it is estimated, cost from $0.5 billion and $2.7 billion per year. Soil erosion is also an issue in Ethiopia, where the siltation of rivers and the clogging of dams may cause Ethiopia's hydroelectric power stations to lose 0.5% of output. The cost of this environmental impact is estimated at $20 million to $170 million per year. Finally, effluent from shrimp ponds in Thailand pollutes common water bodies with nitrogen, phosphorous and other organic materials, leading to eutrophication. The cost of treating this water was estimated at $63 million per year, or about 4% of total shrimp sales.

Man-made fires set to clear land in the Amazon, Brazil

93 The research assumes that 50-70% of the deforestation in the Amazon and 20-30% of the deforestation in the Cerrado can be attributed to cattle. The emissions are allocated to beef production accordingly. The rate of deforestation has decreased significantly in the past two years so the carbon emissions from cattle production for 2009 and 2010 would probably be lower

Pumping water for agriculture on the Chambal river, India

Soil degradation

All the cropping systems studied had noticeable impacts on the health of soils. In the US corn belt, although soil erosion has decreased since the 1980s, the rate of erosion is still estimated at 10 tonnes of soil per hectare per year, which greatly exceeds the natural replacement rate of 0.5-1 tonne per hectare.[94] The cost of this erosion was calculated at $3.3 billion to $5.3 billion a year, based on the lost agricultural output caused by this degradation. This is about 10% of the value of the corn produced. Arable land in the UK can suffer from similar rates of erosion.

Soil health on Indian wheat farms is threatened by a broader set of problems, which include water-logging, salinisation and loss of nutrients, as well as water and wind erosion. One particular problem is that the nitrogen (N) phosphorus (P) potassium (K) mix in fertilisers is heavily weighted towards nitrogen, leading to its over-application relative to other nutrients. In Punjab and Haryana, fertilisers are (because of the subsidy regime) applied in the NPK ratio of up to 27:8:1 instead of the ideal ratio of 4:2:1.[95] Soil fertility is further reduced by the depletion of organic matter in the soil as plant residue is not ploughed back into the fields. The cost of this soil degradation was estimated at $1.7 billion per year, again based on lost agricultural output due to lower fertility.

Water depletion

Most of the agricultural systems chosen for study do not rely heavily on irrigation. In the US, only 15% of corn production is irrigated. Groundwater irrigation for agriculture is estimated to have reduced the volume of water in the High Plains (Ogallala) aquifer by 9% since development began, but the decline is mostly confined to northern Texas and western Kansas, which account for a tiny proportion of corn growing. Therefore it is not clear if the cost of water depletion can be attributed to the corn sector. Farming in the UK and Ethiopia is overwhelmingly rainfed, and agriculture is a negligible factor in groundwater depletion. For example, agriculture accounts for only 0.4% of groundwater abstraction in the UK.

The major exception is wheat production in India, especially in the more productive states of Punjab and Haryana. Here 75% of wells are over-exploited.[96] Some of this high groundwater use can be attributed to the supply of inexpensive or free electricity, which makes excessive use of electric pumps economic. Modelling by IFPRI suggests that if no remedial action is taken, irrigated production in these states may have to be curtailed, leading to a decline in total wheat production in India by around 15% by 2020. The net present value of this loss in production was calculated at about $1.2 billion.

Biodiversity

The most difficult environmental impact to measure is the effect on biodiversity. Even where quantitative data exists on the loss of biodiversity, it is very difficult to ascribe a monetary value to it. The researchers made some attempt, where data could be found. For example, the amount pharmaceutical companies have been willing to pay for bioprospecting rights in the Amazon has been used to derive the biodiversity cost of the deforestation caused by cattle ranching in Brazil, giving a figure of between $400 million and $9 billion. The sheer range of these figures is a good indication of their speculative nature. In addition, bioprospecting represents only a small part of the value of biodiversity. This is one area where a lot more research is needed to allow better assessments.

It is also recognised that this research may not capture all of the ecosystem services affected by agriculture and fisheries, for example the regulation of rainfall and moisture by forests and soils, or the ramifications for the marine ecosystem of using unselective fishing gear. One example for which data could be found relates to the clearing of mangrove forests by the shrimp industry in Thailand. Researchers estimate that each hectare cleared represents a total loss of $10,821 to society from the increased storm damage due to lack of coastal protection from mangrove forests.[97]

Social impacts

It is clear that many of the food production systems have negative environmental impacts and/or rely heavily on public subsidies. Why are societies willing to tolerate systems that seemingly produce such poor value? Is it because these systems deliver valuable social goods – such as food security, poverty alleviation, employment, positive contributions to diet and health – to make up for these costs? The researchers made an attempt to explore some of the social costs and benefits associated with each food production system.

94 Pimental, D. (2006) Soil erosion: a food and environmental threat. *Environment, Development and Sustainability*
95 Ministry of Agriculture. (2010)
96 World Bank. (2010) *Deep wells and prudence: towards pragmatic action for addressing groundwater overexploitation in India.* Washington, World Bank
97 Hanley, Nick & Barbier, E. B. (2009) *Pricing Nature: Cost-Benefit Analysis and Environmental Policy.* 1st edition. Cheltenham, Edward Elgar

The impacts tend to reflect the level of development in each society. For example, corn farmers in the USA have high incomes – in global terms – of about $30,000 and generally good working conditions. The main problems are financial stress caused by low margins and income fluctuations, the pressure on small farms to consolidate, and the decline of rural communities as farms require less labour. Corn farms have very high yields, on average 9.7 tonnes per hectare, and a single corn farmer produces 8 million kcal per day, in theory enough to feed 3,200 people. However, it should be remembered that only a few percent of this corn is consumed directly as food – the rest is used for animal feed or for biofuels, or processed into sweeteners or other forms. Some critics point to the low cost and ubiquity of corn as contributing to the epidemic of obesity in the USA, something which has been estimated to cost $78.5 billion a year.[98]

Farming in the UK during the period studied produced the same outcomes of large food surpluses per farm worker and relatively good working conditions, combined with the stresses that come with volatility in a low margin business.

Agriculture in Ethiopia is at the other extreme. Agriculture is the most important sector in Ethiopia's economy: it accounts for nearly 43% of GDP and 80% of exports, and directly supports nearly 85% of the population. Yet smallholder farmers in Ethiopia struggle to produce enough to feed their own families, let alone to produce a surplus for others. On average, farms produce about 2,100 kcal per family member per day, which is 15% less than their daily requirement. Poor market linkages exacerbate this problem, discouraging investment and inhibiting trade with urban areas. This leaves large parts of the population food insecure: the World Bank suggests that 8% of the Ethiopian population requires food aid year round, while another 8% requires it for at least part of the year. Smallholder farmers also tend to be poor. Their incomes (less than city dwellers, slightly above pastoralists) are generally equal to a national average which is very low – almost 40% of the Ethiopian population live on less than $1 per day and over 75% live on less than $2.[99]

There are a range of experiences within India, with prosperous farmers concentrated in the states of Punjab and Haryana producing large wheat surpluses, while many farmers are mired in poverty, debt and food insecurity. In India as a whole there are more than 230 million undernourished people, or about one quarter of the world total. In Brazil, the beef industry employs 600,000 people and is a major source of protein (and export earnings), but poor treatment of an estimated 25,000 indentured workers on remote ranches is a major social issue.[100]

The fishing industry around the world also produces a range of outcomes. Fishers in the North-East Atlantic Bluefin tuna

Plant health treatment by plane on intensive cereal culture cultivation, Oregon, USA

industry, mostly from France, Spain and Italy, benefit from relatively good wages and working conditions, but their expensive, low-volume catch makes little contribution to food security. The shrimp industry in Thailand also makes a limited contribution to domestic food security, because most of the product is exported, but shrimp farmers earn well above the national average. On the other hand, the coastal fishery in Senegal provides 49% of the country's animal protein, making a crucial contribution to domestic food security, and its 45,000 fishers earn incomes close to the national average, although often in difficult and precarious conditions.

The range of positive and negative social impacts associated with agricultural and fishery systems reflects the diversity of the societies in which they are situated. In some cases – for example, smallholder agriculture in Ethiopia – these systems appear to be under-performing on the social dimension as much as on the environmental dimension. Here, food security and sustainability, poverty and the environment, are certainly intertwined. In almost all the cases, it is arguable whether the social externalities associated with agriculture and fisheries were positive enough to justify the economic and environmental costs.

Vulnerabilities

For each case study, the researchers considered the vulnerability of the food production system to some of the risks or shocks outlined in the previous chapter. The analysis was selective and illustrative – understanding the full vulnerability of these systems would require a more sophisticated, scenario-based, sensitivity analysis. But the results highlight some of the risks that food producers and policymakers should take into account.

High-input corn production in the US is vulnerable to spikes in the price of energy and fertilisers, as input costs account for 37% of total production costs. Although soil erosion occurs at a considerable rate in the US and the UK, this

98 Wang et al.(n.a) Will all Americans become overweight or obese? *Obesity*, 16; See also Pollan, M. (2007) The Omnivore's Dilemma. 1st edition. London, Bloomsbury

99 IFAD (2011) *Rural Poverty Report.* IFAD, Rome

100 Instituto Brasileiro de Geografia e Estatistica (IBGE). Statistics Database. [Online] Available from: http://www.ibge.gov.br/english/ [Accessed 15th January 2011]

poses less of a near-term risk than might be expected as the presence of deep, fertile soils in these regions means that erosion may be able to continue at present rates for fifty or even one hundred years without severely affecting production – although the loss of nutrients intensifies reliance on synthetic fertilisers.

Among the case studies analysed, the agricultural system with the greatest vulnerability is wheat production in India. The high use of fertilisers exposes the country to swings in energy prices. This is a fiscal issue, as large subsidies mean that the government picks up the bill: in 2008, a rapid ascent in international fertiliser prices caused the subsidy bill to balloon to over $30bn, which was almost 2% of GDP.[101] The new strain of wheat rust (Ug99) that has reached Iran from Africa also threatens to devastate Indian crops – only 8% of the wheat varieties grown in India are resistant.[102] The biggest problem is the depletion of groundwater aquifers. IFPRI suggests that water scarcity could cause wheat production to drop by 15% within just ten years. By 2050, the situation would be much worse. These are enormous risks for a country with a growing population that is already food insecure.

Despite its low level of development, Ethiopia smallholder agriculture in the highland agricultural areas studied (as opposed to the pastoral and more marginal regions) appears less vulnerable to future environmental risks. Average rainfall is high, soils are being degraded but still fertile, and climate change models predict little change in conditions over the next 40 years. Farmers are exposed to weather variability, while extreme poverty, limited access to social protection measures, land tenure issues and poor market linkages create their own vulnerabilities. But the natural endowments of this region offer hope that food security can be achieved, once social and economic obstacles are overcome.

In contrast, two of the fisheries studied appeared highly vulnerable. The Northeast Atlantic Bluefin tuna fishery has been severely overfished. The stock spawning biomass has been depleted to around 150,000 metric tonnes, about half of what it was 35 years ago. At this extremely low stock level, Bluefin populations are vulnerable to both continued overfishing and exogenous shocks such as ocean temperature increases or depletion of fish stocks lower down the food chain.[103] While estimates of future stock trajectory are highly contested, continuing to overfish at current levels could force stocks into a state of collapse within the next 12 to 15 years.[104] Intensive shrimp farming in Thailand may be just as vulnerable, because of the threat of disease and storm damage, the latter made worse by clearance of mangrove forests. Moreover, the industry constantly requires new land as farmers abandon ponds once they become too polluted or disease-ridden – there is a risk that suitable land will eventually run out.

Bluefin tuna being transferred in a floating cage

© Parsons/Greenpeace

All the case studies exhibited vulnerability to climate change. The susceptibility of ocean fisheries to temperature rises and ocean acidification has already been noted. In Brazil, a study into the impact of global warming on cattle ranching found that a 1-2 degree Celsius rise in temperature would increase beef production costs by 80-160%, putting Brazil's international competitiveness in doubt. This is due to changing temperatures and rainfall patterns, which would affect pastureland quality and availability.[105] The evidence is ambiguous for the US Corn Belt, because of uncertainty over changes in precipitation. Surprisingly, arable farming in the Southeast of England could suffer more. Although these farms do not rely on irrigation, falling water tables and reduced soil moisture could lead to increased water stress during key parts of the growing seasons.

4.4 Counting the costs

The application of the methodology to various case studies reveals a common theme: that the market price of food does not reflect the environmental costs of its production. Some of these costs are inflicted outside the food production system and onto wider society, for example, the air and water pollution that harms human health. But some of the impacts degrade the ecosystem services on which the food production systems rely on in the first place. Many of our efforts to produce food erode natural capital, robbing future generations of the benefits of these natural resources. If the true costs were internalised by producers and consumers, the economics of agriculture and fisheries would look very different. For example, $100 of farm produce in the UK might

101 ICIS News. (2011) *India's fertiliser import bill to set to go up next fiscal as global prices forecast to rise.* [Online] Available from: http://www.icis.com/Logon/Logon.aspx?RequestedUrl=/Articles/2011/02/01/9440042/Indias-fertiliser-import-bill-set-to-go-up-next-fiscal-as-global-prices-forecast-to.html&ArticleSource=5

102 Singh et al. (2008) Will stem rust destroy the world's wheat crop? *Advances in Agronomy*, 98, 271-309

103 Kimura et al. (2010). Impacts of environmental variability and global warming scenario on Pacific Bluefin tuna apawning grounds and recruitment habitat. *Progress in Oceanography*. Vol 86. Issue 1-2

104 Mackenzie et al. (2009) Impending Collapse of Bluefin tuna in the Northeast Atlantic and Mediterranean. *Conservation Letters*, 2

105 Naas et al (2010) Impact of global warming on beef cattle production cost in Brazil. *Scientia Agricola* Vol 67, No. 1

Figure 17 – Estimating the true cost of food production systems, per $100 of food produced

Product	Corn	All ag.	Beef	Wheat	Mixed ag.	Bluefin	Shrimp	Coastal fish
Geography	USA	UK	Brazil	India	Ethiopia	NE Atlantic	Thailand	Senegal
Market price of food ($)	100	100	100	100	100	100	100	100
Subsidies ($)	17	18	2	19	0	17	9	44
Greenhouse gasses ($)	4	13	62–76	12	50	1	16	15
Air pollution ($)	4–7	1	0	16–32	0	N/A	N/A	N/A
Water pollution ($)	4	1	1–3	1	1–8	N/A	4	N/A
Soil degradation ($)	9–14	10	0.5–1	13	2–18	N/A	N/A	N/A
Water depletion ($)	0	0	0	9	0	N/A	N/A	N/A
Biodiversity loss ($)	1	0.5	0–49	N/A	1–64	N/A	5	N/A
Estimated true cost ($)	135-150	144	166-231	170-186	154-240	118	134	159

Source: ISU case study research

Notes: Costs per output value do not reflect absolute impacts of systems. E.g. Total GHG emissions from beef in Brazil are higher than from smallholder agriculture in Ethiopia, but per value of food produced the figures are similar. Significant uncertainty around biodiversity values. Lack of data on full environmental impacts for marine fisheries.

actually cost $144; the cost of $100 of Brazilian beef might double; the true cost of $100 of farmed shrimp from Thailand may be closer to $134. This is a classic market failure.

Many of the food production systems appeared vulnerable to future risks and shocks, largely because of this erosion of natural capital. Water depletion, climate change, over-exploitation of fishing stocks and heavy reliance on energy-intensive inputs may all result in greater volatility of output and pricing within the next forty years. The most vulnerable systems were in developing countries, the places that are set to experience the greatest population growth and rise in demand. These were also the countries where food production systems produced the worst social outcomes, in terms of poverty and food insecurity.

In many of the systems studied, public subsidies play a major role. But they do not appear to be designed to maximise public goods. They increase farmer incomes and encourage production in the short-term, while keeping food prices low, but, in most cases, they do not encourage farmers or fishers to reduce environmental externalities or to preserve natural resources. Although there are examples of policy beginning to shift towards agri-environmental goals (for example, in the European Union), most subsidy systems tend to be narrowly focused on production, while neglecting the objectives of sustainability and resilience.

5 Towards sustainable and resilient food systems

The world needs food systems that deliver a range of economic, environmental and social goals, while being resilient to risk. There are encouraging examples of systems that do just that. Scaling them up will require new tools of assessment and new economic measures to internalise external costs.

The economic framework in which food producers operate makes it rational for producers to erode natural capital, to push externalities onto society and to ignore some of the long-term production and market risks. So long as producers are not required to internalise the environmental costs of production, and so long as consumers do not pay for these extra costs, it is rational for producers not to take on the extra financing needs and risks associated with the transition to alternative systems. Indeed, many food producers are operating within such tight margins, in a daily battle for survival, that they do not have the luxury of considering alternative approaches. Tackling rural poverty and mal-nourishment in developing countries will be an integral part of any shift towards more sustainable and resilient systems.

5.1 Reasons for hope

The ISU case study research indicates that today, many food production systems give poor value for society, once public subsidies, environmental costs and social impacts are considered. This is true for both conventional, industrial agriculture in high-income countries and for traditional, subsistence agriculture in low-income countries. Moreover, many of these systems are vulnerable to the risks and shocks that have contributed to the current food crisis and that are likely to intensify in the future. At the same time, these systems will be called upon to greatly increase production - the world may need to produce 75% more food by 2050 to meet growing demand. Under these pressures, continuing with 'business as usual' will only lead to further erosion of natural capital, the perpetuation of poverty and greater vulnerability. A transition to a more sustainable and resilient system is urgently required.

The good news is that there are many reasons for hope. There are dozens of examples of alternative production systems that appear to offer better performance and greater resilience. The ISU researchers found some examples when analysing the case studies profiled in the previous chapter and there are plenty more examples in the literature on sustainable agriculture and fisheries. Many are being implemented at a small scale, facilitated by special measures of support. The challenge will be to scale them up and to create the conditions whereby it is in the interests of all farmers and fishers to adopt them.

ISU case studies

The ISU asked the consultants who prepared case studies on current food production to look at possible alternatives that might deliver better outcomes against economic, environmental and social goals. The approach was to identify practices that appear to work on a small scale under comparable conditions, and to model the impacts of scaling them up to a national level. The selection of these alternatives was not the result of a comprehensive analysis of all options. The purpose was not to identify the best alternative but to illustrate how some alternatives appear to produce better results than 'business as usual'. Their inclusion is not meant to act as a recommendation of these alternatives. Indeed, there may be question-marks around the long-term resilience of some of these alternatives as well. Nevertheless, the ideas assessed may point towards 'no regret' moves that will help improve the performance of food systems in the short-term, while a more fundamental transition towards sustainability and resilience is carried out.

The following alternative production systems were modelled for each of the case studies. Further information can be found in Annex B.

- **Beef production in Brazil.** Intensifying cattle ranching on existing pastureland, and avoiding new forest conversion, by (i) improving forage, soil fertilisation and animal breeding; (ii) implementing silvopastoral techniques on degraded pastures; and (iii) implementing integrated crop and livestock systems.
- **India wheat production.** Reducing dependence on fertilisers and groundwater in the states of Punjab and Haryana by optimising irrigation, improving soil fertility, reducing post-harvest losses and leaving land fallow. Improving yields in other states by improving agronomic methods and reducing post-harvest losses.
- **USA corn.** Adopting precision agriculture in some areas, to reduce input use and to increase yields. Introducing more crop rotation in other areas, which would lower corn production but increase production of other crops. Alongside these agronomic changes, the impact of eliminating subsidies was also modelled.
- **Ethiopia smallholder farming.** A three-step approach focused on fertile areas with high agricultural potential, involving (i) improving yields through provision of seeds,

inputs and knowledge on soil preparation, (ii) developing surface irrigation where sustainable, (iii) diversifying production towards more vegetables, cash crops and livestock for domestic markets. Accompanied by improvements in rural infrastructure, market access, and farm credit.

- **UK 'average' farm.** Converting to a 'mixed organic' approach, involving lower crop yields, more diversified production of crops and tubers, and a shift towards less intensive livestock raising. The results are based on a study by the University of Reading on the implications of a switch to organic agriculture.
- **Northeast Atlantic Bluefin tuna.** Allowing the fishery to recover to a sustainable state through robust fisheries management measures such as (i) eliminating illegal, unreported and unregulated fishing; (ii) agreeing a short-term reduction in fishing capacity; (iii) removing capacity-enhancing subsidies; (iv) and implementing gear restrictions, size and age limits and catch documentation. Requires effective monitoring and enforcement mechanisms.
- **Senegalese coastal fishery.** Allowing the fishery to recover to a Maximum Sustainable Yield by reducing catch volumes by 25%. Achieved by reducing fishing capacity, reducing quotas and improving enforcement.
- **Thailand shrimp farming.** A shift to less intensive and less polluting production, involving (i) locating new shrimp farms above tidal zones, (ii) treating effluent from shrimp ponds; (iii) requiring farms to build storage ponds; (iv) lowering production intensity to 4.5 tonnes per hectare. Accompanied by re-allocation of government subsidies.

In all the case studies, the researchers found ways to increase the overall value to society of the food production systems, taking into account the subsidies and the environmental impacts. The 'true cost' of food was brought closer to the market price. For example, the social and environmental costs of $100 of US corn fell from $135-150 to $114-126. The cost of Brazilian beef fell from $166-231 to $122-142. The cost of $100 of food produced by Ethiopian smallholders fell from $167-253 to $114-133. This implies that if conventionally produced food included the environmental costs associated with their production, more sustainable products would become relatively less expensive.

In some cases, more sustainable alternatives involved a decrease in production or a change in the type of food produced, implying a trade-off between demand and sustainability. But in many cases it was possible to maintain or increase production while also reducing the environmental impacts. In developing countries, the alternatives also generated greater income for producers, thereby contributing to poverty alleviation and rural development. Yet, all the more sustainable alternatives studied would involve additional cost for producers, and some implementation risks, certainly in the short-term. It could be many years before they received a pay-back on upfront investment. Therefore, new economic incentives would be required to encourage a shift to these practices. In many cases, this could be achieved by a redesign of public subsidies.

Other examples

The preceding case studies provide some examples of the types of changes that could be made to improve the performance of food production systems, across very different countries and food types. There are many more. In fact, there is a swelling literature on the theme of producing more food with fewer resources in ways that will be more resilient to climate change and other risks. For example, a study of 286 'agro-ecological' initiatives across 57 poor countries showed that farmers benefited from an average yield increase of nearly 80%. The study covered 12.6 million farms over 37 million hectares, or 3% of the cultivated area in developing countries.[106]

The ISU has catalogued over seventy examples of sustainable and resilient agriculture and fishery systems around the world. A full list is contained in Annex C and some have been profiled on the following pages. They have been analysed in terms of whether they address the risks explored in previous chapters – exposure to external energy and input prices, degradation of soils, water scarcity, vulnerability

Figure 18 – Comparison of 'true costs' of food under current and alternative systems

Product	Geography	Market price ($)	True cost ($): current system	True cost ($): alternative system
Corn	USA	100	136-150	114-126
All ag.	UK	100	144	138
Beef	Brazil	100	166-231	122-142
Wheat	India	100	170-186	153-168
Mixed ag.	Ethiopia	100	154-240	114-133
Bluefin	NE Atlantic	100	118	101
Shrimp	Thailand	100	134	143
Coastal fish	Senegal	100	159	116

Source: ISU case study research

106 Pretty, J. (2009) The top 100 questions of importance to the future of global agriculture. International Journal of Agricultural Sustainability, 8 (4), 227-236

After restoration of the Loess Plateau in Hou Jia Gou Shaanzi

to pests and diseases, loss of biodiversity or ecosystem functionality, weather volatility or climate change, and poverty, inequality and underdevelopment.

In most cases, the catalyst for action was when the exacerbation of a long-running problem led to a rapid fall in food production or spill-over impacts for wider society, sufficient to provoke local communities, governments or NGOs into action – i.e. some sort of tipping point was reached. This led to innovation, often in the form of a certain technology, although these technologies could range from the advanced, capital intensive options to more basic interventions. For example, technologies that address water issues range from high-tech precision irrigation systems in Australia,[107] to more simple water harvesting techniques in Mali that divert scarce rainfall into small areas of crops and trees.[108]

The analysis showed that water scarcity, soil degradation and reliance on inputs were the most frequently addressed problems. However, even when innovations were targeted at these risks it was found that they often strengthened resilience to other risks and helped improve the functioning of the overall system. The most successful schemes had spill-over benefits in terms of controlling pests and diseases, increasing biodiversity, reducing greenhouse gas emissions, and decreasing vulnerability to climate volatility. These examples also tended to produce important economic and social benefits. Economic benefits came from an increase in yield, the generation of more stable revenue through diversification, or the lowering of operating costs (for example, by reducing energy or input costs). Yield increases from sustainable agriculture techniques could be enormous, ranging up to 350%. The associated social benefits included better social cohesion, improved livelihoods, the introduction of new skills and knowledge, better food security and the empowerment of women. In all these cases, better use of natural resources went hand in hand with social and economic development.

Many of the most impressive farming examples come from developing countries, as this is where the greatest opportunities exist for simultaneous increases in yields, incomes and environmental sustainability. But there also plenty of examples from OECD countries, ranging from modest attempts to reduce the polluting effects of intensive agriculture to more radical redesigns of farming systems. It should be remembered that the environmental performance of agriculture in OECD countries has begun to improve. Since 1990, the extent of soil erosion and the intensity of air pollution have fallen; the amount of land used has decreased even as production has increased, and there have been improvements in the efficiency of the use of fertilisers, pesticides, energy, and water.[109] Better regulation and 'smart' subsidies can help accelerate this process.

In fisheries, the ISU has also studied more than sixteen examples of successful transitions from over-exploitation to sustainable marine resource management, in both OECD and developing countries. These programmes have delivered a similar range of environmental, economic and social benefits. Most importantly, they have helped preserve the marine ecosystems on which the fishing industry depends on.

107 Land and Water Australia (2006). *Futures: Review of farmer initiated innovative farming systems*. Canberra
108 Moorhead, A (2009) *Climate, Agriculture and Food Security: A Strategy for Change*. Alliance of the CGIAR centres
109 OECD. (n.a) *Environmental performance of agriculture in OECD countries since 1990*

Building resilience: the Loess Plateau example

Many of the examples cited above have been implemented on a small scale. But there is at least one example of transformation on a very large scale. It has taken place over the last two decades on the Loess Plateau in Northwest China, on an area covering 15,600 km2. It brings together many of the themes that have been explored in this report - the fragility that comes from environmental degradation; the need for a cross-sectoral response that addresses the issues of water, soils, energy, food and poverty; and the multiple benefits that can arise from the transition to sustainable and resilient agriculture.

By the early 1990s, the farming system of the Loess Plateau seemed to be in terminal decline and heading for collapse. Decades of over-cultivation and over-grazing, combined with uncontrolled logging, had stripped the soil from the hilly landscape, reduced water availability and devastated food productivity. The area is home to more than 50 million people so the potential socio-economic consequences were severe.

In response to the challenge of land degradation, Chinese planners from the Ministry of Water Resources, working with partners from the World Bank and other institutions, conceived the Loess Plateau Watershed Rehabilitation Project. In a multi-stakeholder process, the land was divided into two broad zones. On the hills, a ban was placed on the free grazing of goats, and a reforestation programme was carried out to stem soil erosion and to improve water retention. The second zone, consisting of the valleys and shallow slopes, was designated for conservation farming. Local people used terraces to create viable agricultural fields, planted orchards and used greenhouses to cultivate new high-income crops. Instead of rangeland grazing, fodder for animals was cultivated. The cultivation of pigs in backyards provided a source of protein, fertiliser and fuel. This meant that trees could be spared as they were no longer needed for fuelwood. The creation of a network of small dams helped to store rainwater for dry seasons. This was accompanied by land tenure reforms which allowed farmers to fully benefit from the sale of produce and the improvements made on their land.

The results have been impressive. Perennial vegetation cover increased from 17 to 34%. Sediment flows from the Plateau to the Yellow river have been reduced by more than 100 million tonnes each year. Most importantly, food supplies have been secured. Terracing has not only allowed increased average yields but also significantly reduced their variability. Farmers have moved from producing a narrow range of food and low value grain commodities to much higher value produce. But grain production has grown as well: over the second half of the project, per capita grain output increased from 365kg to 591kg.[110]

According to The Royal Society, a sustainable production system exhibits most of the following attributes:

1. Utilises crop varieties and livestock breeds with high productivity per externally derived input
2. Avoids the unnecessary use of external inputs
3. Harnesses agro-ecological processes such as nutrient recycling, biological nitrogen fixation, allelopathy, predation and parasitism
4. Minimises the use of technologies or practices that have adverse impacts on the environment and human health
5. Makes productive use of human capital in the form of knowledge and capacity to adapt and innovate and social capital to resolve common landscape-scale problems
6. Quantifies and minimises the impacts of system management on externalities such as GHG emissions, clean water availability, carbon sequestration, conservation of biodiversity, and dispersal of pests, pathogens and weeds

Royal Society, (2009). *Reaping the Benefits: Science and the Sustainable Intensification of Agriculture.*

Suggested principles

The variety of examples cited so far indicate that there is no single model for a sustainable and resilient food system. It will depend on the specific circumstances of a country, region or food type. However, some common themes have emerged from the ISU's research. These ideas are gaining greater acknowledgement from governments, NGOs and multi-lateral agencies.[111]

One theme is that systems that work with biological and ecological processes, and make efficient use of external inputs, tend to be more sustainable and resilient. There are a range of agro-ecological farming practices that have been shown to work. They include conservation tillage, improved fallows, crop rotations, inter-cropping, use of nitrogen-fixing fodder and green manure cover crops, recycling of crop residues and other wastes, rotational herd grazing, integrated biological pest management and agro-forestry, to name a few. Rather than simple high-input, high-output systems, in the future more sophisticated ways will need to be found to manipulate natural energy, carbon, mineral and water cycles to produce food.

Another theme is the importance of maintaining intra and inter-species diversity. Biodiversity serves as insurance against environmental changes by increasing the system's adaptive capacity. There are strong arguments for preserving farming biodiversity (traditional crops and animals), as well

110 World Bank (2007). Restoring China's Loess Plateau. http://www.worldbank.org/en/news/2007/03/15/restoring-chinas-loess-plateau
111 See IAASTD, (2009); Foresight, 2011 (b); World Bank, 2008; UNEP, 2011; Evans, (2009)

CASE STUDY: A balanced farming system in Iowa, USA (The New American Farmer 2nd Edition, 2005)

PROBLEM: Dependence on a high-input system. Farms suffered from serious soil erosion blowing away on windy days and washing away during rainstorms. The fields were cultivated all year round and the crop residue burnt to avoid clogging and damaging the machinery.

INNOVATION: Due to dissatisfaction with the status quo on behalf of farmers some have transitioned to a more balanced farming system with a reduction in purchased chemicals. An example of this is a five year rotation system which includes corn, beans, corn, oats and hay with livestock. A 'ridge-till' method can be used that leaves the soil undisturbed from planting to harvesting. At planting this is then sliced off and thrown back between the rows which helps to suppress weed growth thus almost eliminating the need for herbicide and insecticide. As a closed loop system the manure from the livestock acts as a natural fertiliser.

COSTS AND BENEFITS: Diversifying reduces financial risk as money does not need to be borrowed to plant crops. On a 16 year average, one farmer has calculated that his conventional farmer neighbours on average lose $42 per ha (after subsidies are taken out) whereas he generates a profit of $114 per ha: a difference of $156. The farm has not received subsidies for some years but still supports two families without off farm employment and no organic premium. The diversified system reduces costs associated with weed management by $25 per hectare and using on-farm manure reduces fertiliser costs by a further $25 per hectare. Environmentally, benefits result from a significant reduction in soil erosion and a build up of soil organic matter.

CASE STUDY: Crop-livestock rotations with zero tillage, Brazil (Landers et al, 2005)

PROBLEM: Land degradation leading to land clearing and associated deforestation.

INNOVATION: Integrated Crop-Livestock rotations with Zero-Tillage (ICLZT). This technique uses synergy and symbiosis to maximise production from more and more scarce land and resources. Zero-tillage leaves biomass on the surface of the soil which builds soil fertility up naturally by increasing the Soil Organic Matter and improves nutrient recycling. The ICLZT system rotates high-yielding pastures with crops. The ZT phase supplies residual nutrients for cheap pasture and the pasture phase reduces pests, weeds and disease levels. The most common rotations are a combination of soybeans, cotton and maize followed by one to three years of pasture.

COSTS AND BENEFITS: Economically, these techniques have a beneficial effect of by trebling pasture stocking rates, increasing net present value and internal rates of return for the farmer. These practices have led to the reversal of soil degradation by building up organic matter and soil carbon levels reducing the needs and costs of synthetic control measures. Soil loss is 79% reduced under ZT and surface runoff is 69% reduced increasing aquifer recharge, compared to conventional tillage. The average economies of ZT to the Brazilian economy are about $2bn. Studies have shown mitigation potential of ICLZT as between 0.8 and 2.5ha of reduced demand for deforestation per hectare of land farmed with ICLZT.

CASE STUDY: Zero tillage in the Pampas, Argentina (Billions Fed, IFPRI)

PROBLEM: During the 1970s the Pampas region in Argentina had a high risk of soil degradation. Burning the land after the previous crop had finished was the standard practice and began to undermine productivity even in the most well endowed areas.

INNOVATION: The establishment of a farmer-driven network brought together multiple stakeholders in order to adapt to the zero tillage needs of the Argentine Pampas. Zero-tillage, a resource-conserving practice that depletes organic matter at a lower rate than conventional practices and improves the soil water retention, was introduced. This involves the use of herbicide tolerant strains of soybean and the herbicide glyphosate which breaks down previous crops and returns nutrients to the soil. This enabled farmers to plant again very quickly and coupled with the use of drillers rather than ploughs meant that soil erosion was minimised.

COSTS AND BENEFITS: Argentine production of soybeans grew from 26m to 67m tonnes in just over a decade. Argentina is now the third biggest exporter of soybeans. About 8.3% of the total value of production can be attributed to zero tillage. Enormous cumulative savings were generated for farmers and about 200,000 new jobs created, as well as the generation of large amounts of research on best practice. Soil fertility has improved greatly and the initiative was able to reverse decades of degradation and unsustainable land exploitation.

CASE STUDY: Agro-forestry using the Faidherbia tree in Sub Saharan Africa (World Agroforestry Centre, n.a)

PROBLEM: The production of crops such as cotton, maize and sorghum deplete the natural nutrients found in soil. The soil degenerates unless this fertility is continually restored either organically or synthetically. This can increase costs and be damaging to the environment.

INNOVATION: Research on Faidherbia as a fertiliser tree began thirty years ago when scientists noticed farmers retained these trees on their land and realised they were part of a traditional system. Additionally, in Niger, regulatory reforms meant, amongst other things, that farmers could "own" the tree on their land so it was worth their while to look after it and put it to longer term productive use. The tree thrives on a range of soils, is indigenous and occurs in ecosystems from deserts to wet tropical climates. It is a nitrogen fixing plant and has 'reversed leaf phenology' which makes it dormant and shed its leaves during the early rainy season and leaf out during the dry season - so it is compatible with food production as it does not compete.

COSTS AND BENEFITS: Reports of productivity increases range from 6% to more than 100% and are particularly remarkable in places of low fertility. In Malawi they were increased by 280% and in Zambia from an average of 1.3t/ha to 4.1t/ha. To date the innovation has been used on 600,000 ha in Zambia (160,000 farmers). In Niger more than 4.8m ha have been planted. Trees provide a natural form of fertiliser that is free, sequester carbon and prevent the use of synthetic nitrogen fertilisers, protecting farmers from rising world input prices. The goal is to scale this to the 50m farmers who need to enhance food security in a climate change vulnerable environment.

CASE STUDY: Integrated fishponds, vegetables and livestock in Northern Vietnam (FAO, 2001)

PROBLEM: The nutritional standard of the rural poor in Vietnam was very low. Due to decades of war, Vietnam's agriculture was seriously set back. Malnutrition was widespread in rural areas and many families were only cultivating rice.

INNOVATION: The importance of small-scale integrated farming was emphasised by President Ho Chí Minh in the 1960s because of population rise and rural malnutrition. The practice grew gradually in popularity from then on, but the establishment of the Association of Vietnamese gardeners (VACVINA) in 1986 gave the system the extra promotion it required. It promoted a system of small-scale, intensive farming in which the home, garden, livestock and fishponds are integrated (VAC system). Crops are grown in the garden without chemical inputs and several species are intercropped to make full use of water, sunlight and soil nutrients. Fruit trees are often interspersed with the vegetables, which grow in their shade. A variety of fish are reared in the pond, making use of different water depths. Pigsty and poultry sheds are situated close to the pond and their manure is used for plant and fish food, while various garden products are used to feed the livestock and fish. The farmer's family consumes or sells produce and contributes organic waste to the system. Pond silt can also be used as fertiliser. The original VAC model has been modified to suit Vietnam's three principal ecological regions: the coastal areas, the deltas and the uplands.

COSTS AND BENEFITS: The VAC movement has played an important role in improving people's lives, diversifying Vietnamese agriculture and environmental protection. It is labour intensive but it provides productive employment for people of all ages because hard manual labour is not required. Most farmers can achieve surplus produce for the market within 6 months to 2 years of starting work and 30-60% of the income of most village families now comes from their VAC system. Annual income from VAC farming is 3-5 times higher than that derived in the same area from growing two rice crops per year. It has also been very successful in achieving the original goal of reducing malnutrition. These systems have profound advantages for sustainability in terms of recycling animal wastes and utilising other by-products.

CASE STUDY: The New Zealand Fishing Industry (Statistics New Zealand 2010)

PROBLEM: During the 1970s and 1980s increased fishing effort on the offshore grounds around New Zealand had resulted in declining catches, reduced profitability and overfished stocks.

INNOVATION: There was a recognition that that the economic potential of sustainable harvesting from fish stocks within the New Zealand economic zone was enormous and was being lost as a consequence of overfishing and poor fisheries management. In 1986 New Zealand introduced the world's first rights-based fisheries management system. This allocated fishing quotas to individual fishermen and fishing companies based on historic fishing performance. These Individual Transferable Quotas (ITQ) can be bought, sold and leased and, as a result, there was potential for a fundamental rationalisation of the industry with quota trading removing excess fishing capacity and thereby making the remaining fleet profitable.

COSTS AND BENEFITS: The operation of the ITQ system over a period of time, together with effective enforcement and improved fisheries science, resulted in fish stocks being rebuilt. The trading of quotas, together with improved fish stocks, restored profitability to the fleet, albeit one reduced in size. The total catch of the New Zealand fleet is currently around 450,000 tons. These days seafood exports rank as the country's fifth largest export earner. Not only were subsidies removed from the fishing industry as profitability returned, but more recently the Government has implemented a cost recovery program whereby the industry funds the cost of managing fisheries in terms of fish stock research and enforcement. This rights-based management system has fundamentally improved the sustainability of fish stocks and, in recognition of this, New Zealand fisheries were ranked in 2009 as the most sustainably managed in the world.

Maize yields beneath Faidherbia trees are often higher than yields beyond the canopy. Faidherbia provide natural fertiliser, timber and fencing for cattle enclosures.

as wild biodiversity, as this can provide a source of traits for future breeding efforts. And, of course, functioning marine ecosystems are critical to the future productivity of marine fisheries. Ecosystem-based fisheries management will have to be at the core of the management of this resource.

Sustainable and resilient food production systems tend to be highly knowledge-intensive. They require a multi-disciplinary understanding, one that encompasses biology, agronomy, ecology, hydrology, chemistry, economics, sociology and meteorology at the level of the field, the farm and the landscape. These farming systems require highly-trained land managers, rather than low-skilled machinery operators. More scientific research into the microbiology and nutrient cycles of soils will be needed, as these areas are still little understood. Marine research must also be stepped up – sustainable fisheries will require a much better understanding of the complexity of marine ecosystems. New technology will undoubtedly play an important role, for example the use of precision technology; and the process of breeding new variants of crops and animals to overcome environmental challenges will continue, as it has done for thousands of years. But much can be achieved with the tools and technologies available now. Indigenous knowledge can often provide a good point of departure.

A final theme is the need for resilience-based stewardship of food production systems. As explored earlier, resilience is difficult to measure, because of the complex nature of the risk environment and the dynamic way in which production systems react to it. This is why adaptive capacity and active adaptive management are key. This means fostering biological, economic and cultural diversity; fostering a mix of stabilising feedbacks and creative renewal; promoting social learning through experimentation and innovation; and adapting governance to changing conditions.[112] It means managing at a landscape level, developing mosaics of sustainable production systems that support one another, and understanding the linkages between food, energy, water, rural economies and cities.

Addressing demand

Although the focus of this report is on food production, opportunities to change the demand side of the equation may assist the transition to a more sustainable and resilient system. The greatest opportunity is reducing food waste. It is estimated that 30% of all food grown worldwide is wasted (although some studies put the figure as high as 50%). In industrialised countries, this waste tends to occur at the point of the consumer – people throw out food that is deemed to have gone off. In developing countries, most of the food is lost on the farm, or during transport, processing or retailing, because of inadequate storage. Halving the amount of waste would reduce the food required by 2050 by an amount equal to 25% of today's production.[113] Similar improvements could be made to fisheries by minimising by-catch and waste along the value chain.

Tackling food waste is increasingly recognised as a 'win-win' solution that decreases pressure on natural ecosystems while increasing economic efficiency and saving money. In

112 Resilience Alliance (nd). *Assessing resilience in socio-ecological systems.* Resilience Alliance, Stockholm

113 Foresight, (2011)

this regard, it has been compared with the role of energy efficiency in energy policy. Reductions in food waste could allow production to decrease, and farm and fishery prices to rise, without consumers feeling the direct impact. As well as absolute reductions in waste, there are also many opportunities to recycle waste back to farming and aquaculture systems, in the form of feed for animals and fish or fertiliser for fields, thus helping to 'close the loop' on nutrient cycles.

More fundamental changes in the nature of food demand may also be possible. It has already been noted that the world produces more than enough food to feed the current population but that much is diverted to animal feed and biofuels. Similarly, the over-consumption of unhealthy foods in industrialised countries leads to obesity and diet-related diseases that have a huge cost for society: in the USA, obesity may already cost $78.5 billion per year; in the UK it is estimated that it could cost approximately £45 billion a year by 2050.[114] Changes to diet and demand in developed countries, which would in themselves reduce the societal costs of over-consumption, could facilitate a transition to more sustainable and resilient levels of production. The intelligent design of bio-energy policies could have the same effect.

5.2 The economic case

As seen earlier, the 'true' economics of food production systems can look very different when environmental externalities and the depletion of natural assets are taken into account. Yet, even in traditional economic terms, there is a strong case for making a transition to more sustainable and resilient systems.

The size of the prize

The economic benefits have been illustrated by a modelling exercise conducted by the United Nations Environmental Programme as part of its 'Green Economy' initiative.

UNEP assumed that 0.16% of global GDP is invested in the 'greening' of agriculture per year between 2011 and 2050 (on average $198 billion per year). Echoing some of the themes in the previous section, this would be invested across four areas: environmentally-sound management practices; reducing pre-harvest losses; reducing food waste and improving processing; research into, and development of, sustainable agriculture and fishery practices. The results were compared with a 'business as usual' scenario, where the same amount of additional investment was made in conventional and traditional agriculture.

According to the UNEP model, the total economic value-add of agriculture and fisheries would be $293 billion per year higher under the 'green agriculture' scenario than for business as usual, an 11% increase. Food production would also be higher, without requiring more land. Forty-seven million more jobs would be created over the next 40 years. The green investments would lead to improved soil quality, less water use, lower greenhouse gas emissions and 19% lower energy consumption than business as usual. UNEP also estimates that there would be sufficient agricultural wastes and non-food crops grown on marginal land to allow large-scale production of second generation biofuels, contributing almost 17% of world liquid fuel production by 2050.[115]

The economic logic for reforming fisheries management is especially compelling. Even if the environmental and social externalities are excluded, global fisheries currently operate at a net economic loss of $5 billion per year, after the approximately $16 billion of public subsidies are taken into account. More and more resources are being used to catch the same amount of fish. In contrast, the World Bank estimates that fisheries could deliver $50 billion more in profit each year, if managed in an optimal manner. In many of the world's fisheries, the total catch would actually increase, if fishing efforts were reduced to allow stocks to recover.[116] The result, in the long-term, would be more fish, more profits and secure jobs.

Achieving economic resilience

Too often, environmental sustainability is considered as coming at the expense of wealth and economic growth. In contrast, the ISU's research shows that increased food productivity, higher incomes and sustainable use of natural resources go hand in hand. Indeed, in developing countries it is hard to see how poverty can be alleviated without agricultural development. 'Agriculture has special powers in reducing poverty', according to the World Bank.[117] It is twice as effective at reducing poverty than growth in other parts of the economy. From England in the eighteenth century, to Japan in the nineteenth century, to China and India in the late twentieth century, agricultural revolutions have prepared the ground for the rise of industry. This is even more important now, because most of the population growth in the next fifty years will occur in developing countries and because these countries have under-utilised natural resources that could support large productivity increases.

Smallholders will play a crucial role in this development. 500 million smallholder farms worldwide support around two billion people, or one third of humanity. They are responsible for producing about 70% of all food. There is an extensive literature demonstrating that small farms make more efficient use of land and capital than larger enterprises – i.e., they produce the most food per hectare. They have the best knowledge of local conditions and they have strong incentives to work hard and to manage their resources

114 *Guardian*. (2007) Obesity crisis to cost £45bn a year. *The Guardian*; Wang et al.(n.a) Will all Americans become overweight or obese? *Obesity*, 16
115 UNEP. (2011) *Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication*. www.unep.org/greeneconomy, UNEP
116 World Bank (2009). *The Sunken Billions : The Economic Justification for Fisheries Reform*. Washington
117 World Bank. (2008) *World Development Report 2008*. Washington, World Bank

Fishing vessel in New Zealand waters

efficiently. (It should be noted that their labour productivity is often lower.) Moreover, in labour-abundant economies, the development of small farms makes the greatest contribution to poverty alleviation and rural development. Vietnam and Thailand are good examples of countries that have achieved food security and impressive economic growth, as well as becoming net exporters of food, through the development of their smallholder farming sector. Land tenure reforms played a big part in this achievement.[118]

The reform of our food production systems will also have fiscal benefits. Many countries, both rich and poor, are locked into the provision of expensive subsidies to farmers and fishers. Energy and fertiliser subsidies can make government hostage to global energy markets over which they have no control, causing budgets to balloon out of control when energy prices rise. There is also the fiscal cost of responding to food security crises, both for domestic governments and for international donors. A shift towards a sustainable and resilient rural development model will reduce the fiscal risks and promote the sort of economic growth that will eventually lead to higher government revenues. It will also facilitate a managed transition of developing economies from agriculture and fisheries towards industry and services. It is better that people migrate to cities because of the pull of better employment prospects, not be pushed out of rural economies because of desperation.

What impact will the transition to a more sustainable and resilient system have on food prices? Global prices may not return to the historically low levels that prevailed before 2007. As already discussed, these prices often did not reflect the true costs of production, once public subsidies - and the free subsidies provided by the environment - were take into account. There are ways to offset higher prices, by changing how food is consumed, reducing food waste and increasing 'food efficiency'. Nevertheless, the focus should be on raising incomes and making sure that people can afford food. Here, a shift to a more sustainable and resilient food production system can help alleviate rural poverty, slow urban migration and contribute to broader economic development within developing countries. Higher incomes from more productive agriculture and fisheries will tend to improve the affordability of food for large sections of the population who currently suffer from hunger. Improvements in the fiscal position of governments should also facilitate the creation of social safety nets for the urban poor.

In any case, the poor are already suffering from the effects of high food prices, brought about by the global food crisis. The era of cheap food may be over. Continuing with 'business as usual' is likely to lead to further volatility and further crises, as the erosion of natural capital intensifies. Some of the policy responses being considered now may help to reduce price volatility in the short-term, but supply shocks and price spikes will recur if dependence on rising energy costs, depleting water and soils, the loss of biodiversity and ecosystem functionality and climate change go unchecked. In the long-term, only a transition to a sustainable and resilient system will produce food at a price that people can truly afford.

5.3 Moving forward

There are clear advantages to be gained from the transition to more sustainable and resilient food systems. The ISU suggests two broad set of actions that should be explored to move this agenda forward: developing an analytical tool that will help policymakers assess the costs and benefits of different systems; finding ways to change the economic frameworks in which food producers operate.

Developing an analytical tool

The case studies prepared by the ISU illustrate that building sustainable and resilient food systems requires a diverse set of actions, different from commodity to commodity and from country to country. There is no one simple prescription. Instead, what is needed is a practical tool that will allow policymakers and food producers to understand the costs, benefits and risks of different options and the risks associated with them.

This tool must capture the multi-functional nature of agriculture and fisheries. Food systems must deliver multiple goals at once. These could include the following:

- **Economic productivity:** provide sufficient quantities of nutritious food in an economically efficient way, while making effective use of public resources
- **Environmental impacts:** minimise negative external impacts on ecosystem services, minimise the depletion of scarce natural resources, and build natural capital
- **Social impacts:** contribute to food security, human health, wealth creation, vibrant communities and cultural values
- **Resilience:** have the capacity to avoid, repel or adapt to risks and shocks, such as climate change, resource depletion, biodiversity loss, disease or trade shocks.

118 Wegner,L & Zwart,G (2011) *Who will feed the world? The production challenge.* Oxfam

In the past, much policy was focused on one goal – maximising productivity. The general approach has been to reduce farmgate prices and to externalise environmental costs. In the future, the other goals will be just as important. This may involve trade-offs, although the search should be for systems that deliver good outcomes against all the goals. It will be important to understand how systems perform at multiple levels – the farm, the fishing fleet, the community, the region, the country, the world. It will be equally important to take a full systems approach and one that encompasses the entire supply chain from raw materials to end of life. This means not just looking at food production but understanding the linkages with food demand, food waste, land use, energy, trade and economic development. An integrated approach is needed, one that assesses the costs and benefits across multiple dimensions and at different scales.

There is a range of analytical tools and frameworks in existence that have been developed by businesses, NGOs, academic bodies or multilateral organisations in order to help assess sustainability criteria. (An illustrative selection is described in Annex D.) These vary greatly. Some are specific in focus, looking just at one particular aspect of sustainability such as carbon (e.g., the FAO EX-ACT tool), others look across the whole supply chain, 'from farm to fork', such as the many Life Cycle Analysis tools that exist (eg. the EU developed CEDA tool) and some are broader frameworks (e.g. the Natural Step Framework). Some are designed for a specific audience, such as farmers, to help assess their own sustainability (e.g. the RISE tool), some are designed for businesses to enable more informed decision making about the products they are buying (eg. the Footprinter tool) and some are designed for policy makers, whether at a national or international level (e.g. the WFP CFVAM tool). Some are quantitative, others are qualitative. Most tools reflect the focus areas of the organisations that developed them, whether biodiversity conservation, carbon mitigation or social vulnerability. What is needed is an analytical tool or framework that is comprehensive, encompassing social, environmental and economic dimensions, and that can be applied at multiple levels. A tool such as this would help policymakers assess the risks associated with food production systems and enable them to make more informed policy decisions.

The methodology developed by the ISU for its case study research, although imperfect, could be one input into the development of such a tool. But much more work would be needed to show the linkages with entire food systems and to allow more dynamic modelling of future risks and scenarios. Much work is also needed to gather the underlying data that will be essential to the functioning of such a tool. For example, the researchers commissioned by the ISU found relatively good data on the environmental impacts of farming in the USA and UK, but much less data on developing countries. Across all geographies, it was difficult to value ecosystem services such as biodiversity. A worldwide effort of monitoring, measuring and research is needed to fill the gaps.

Changing the economic framework

There is an overwhelming body of evidence to show how agriculture and fisheries are eroding natural capital across the world at an alarming rate, contributing to the recent food crises and posing significant risks for the future. The research commissioned by the ISU indicates how the environmental impacts of production systems are not reflected in the price of the food – the true costs of these systems are often considerably higher than the prices paid. Why is this? The simple answer is that food producers have been able to externalise these costs and therefore pursue activities that provide the maximum economic return, in 'simple' terms. The costs fall on society as a whole, or on future generations. The risks are only revealed when systems begin to fail and a crisis occurs. Only by changing the economic framework will producers have the incentive to pursue more sustainable and resilient practices.

One way to do this is to introduce measures that will internalise the environmental and social costs. The choice of measures will depend on local circumstances and political preferences. Markets can be created, for example for water usage or carbon emissions, thereby putting a price on what was before a free resource. Taxes and regulation can be used to discourage certain activities, for example air and water pollution, thereby making sustainable practices appear more attractive. Incentive schemes may be just as effective, for example Payment for Ecosystem Services (PES) initiatives that pay landowners for the water regulation, biodiversity preservation and climate stabilising services they provide: Costa Rica has achieved some notable success in this regard.

Transitional finance can play an important role, especially as some of the sustainable alternatives identified by the ISU require high upfront investment before producing a return. Credit can be provided to landowners and fishers, perhaps on concessional terms, to encourage such investments. Incentives and risk mitigation measures can be introduced to encourage private capital to flow to sustainable production activities. Public-private partnerships can be explored for large investments, where appropriate.

The reform of subsidies is perhaps the most immediate way that policymakers can bring about change on the ground or on the seas. Public subsidies for fisheries are about 30% of total revenues. For agriculture, public subsidies comprise 22% of producer revenues in industrialised countries and a substantial amount in many middle income countries. Subsidies can have positive effects. In Malawi, for example, judicious use of fertiliser subsidies has improved soil fertility and food productivity. In the European Union, the subsidy regime is being progressively decoupled from production and re-oriented towards rural development and environmental goals. Yet, in many parts of the world, subsidy programmes are doing little to incentivise sustainable practices. In some cases, subsidies are encouraging the over-use of fertilisers, fuel or water. Public money is being used across the world to encourage activities that have high costs for society. Instead, public money should be used for public goods. In this way, subsidies could play a vital role in financing the transition to new models.

A special note should be made about global public goods. Some of the negative impacts of food systems described in this report are felt within the same country: for example, air or water pollution, the depletion of soils or local water reserves. But others, such as the contribution of greenhouse gas emissions to climate change, are essentially global costs. It may be neither feasible nor fair to expect countries, especially developing ones, to internalise the costs associated with these emissions. Instead, global agreements are necessary to assign responsibilities and to generate sources of finance. The REDD+ framework is one example of a global initiative that could generate funds to help agriculture in tropical forest countries develop in a way that does not threaten carbon-rich forests. It will also be important for agriculture to be fully included in any future agreement within the United Nations Framework Convention on Climate Change (UNFCCC).

Agriculture is uniquely implicated in climate change: it is a major source of direct and indirect emissions, it is a means of sequestering carbon and therefore counter-balancing emissions from other sources, and it is in need of adaptation to avoid the effects of climate change. Similarly, global frameworks such as the Convention on Biodiversity (CBD) may be needed to create incentives for countries to preserve globally important biodiversity.

Whether through global agreements, or national markets, taxes, regulation or incentives, or transitional finance, ways should be found to change the economics of food production. Farmers and fishers can then be left to find the best ways to produce food, working within these sustainable and resilient parameters. The advantage of this approach is that policymakers are not required to pick the best systems or to instruct food producers on what they can and cannot do. Instead, farmers and fishers can be relied upon to innovate – as they have done with so much success for thousands of years.

6 Next steps

The goal of the ISU is to help build consensus on how the world can respond to the challenges of food security and depleting natural capital. It will continue to collaborate with governments, NGOs, academics and the private sector to find workable solutions.

The ISU plans to undertake three main activities to advance the transition to sustainable and resilient food systems.

First, the ISU will support the development of practical tools that can help assess and strengthen the resilience of food systems. Although considerable research has been done on the risks and challenges facing agriculture and fisheries, there is less clarity on what should be done to reduce these vulnerabilities. A collaborative, multi-disciplinary effort could help generate practical tools that can be used by policymakers. This will mean bringing together experts from government, the private sector, academia and civil society to discuss how risks can be better measured. It will involve understanding the policy-making tools that currently exist and, if necessary, catalysing the development of new tools that encompass the many dimensions of resilience and that place the options in a proper economic context. Addressing data gaps will also be part of this effort. The ISU may work with countries that are interested in applying such tools to assess the resilience of particular food systems.

Second, the ISU will work with the private sector to see how their business practices can assist the transition to more sustainable and resilient food systems - recognising that many initiatives with producers, manufacturers and retailers already exist. The ISU will focus on three goals. One is incorporating the private sector into the debate on how to strengthen the resilience of food systems, in particular exploring how the environmental and social risks identified in this document are likely to affect business operations. Another is working with agribusinesses in rainforest countries to develop models for how food production can be increased without the clearing of more forests. Finally, the ISU will work with investment and finance institutions to explore how private capital can be channelled towards sustainable agriculture in developing countries.

Third, the ISU plans to continue with a more focused programme on fisheries. It will use the findings from its research to develop a better understanding of the economic opportunity of transitioning from ‘business as usual’ to sustainable fisheries management and the need to provide positive incentives for the implementation of the ecosystem approach, robust fisheries management and sound economics. The ISU will work with the fishing industry and other key stakeholders to explore what technical and financial support might be required to make this transition, with the aim of helping to catalyse an increase in the scale and number of best practice examples. The ISU also intends to work with seafood buyers, recognising that increasing the demand for sustainable seafood will continue to play a major role in helping fisheries to transition to sustainable management.

Annexes

ANNEX A

Summary of methodology for assessing food production systems

The ISU commissioned an external consulting firm to assess the sustainability of particular agricultural and fisheries systems around the world. A methodology was designed to determine the net value of these systems accounting for the full range of their costs and benefits (economic, environmental and social) whilst also exploring their vulnerability to future risks. The methodology was applied to eight case studies of agricultural and fishery production systems worldwide, the results of which are summarised in the next annex and discussed more fully in Section 3 of the main report. In compiling the case studies, a number of limitations and potential areas for future development were identified. Application of the methodology to fisheries varies from agriculture in some dimensions: this is discussed further in a separate ISU report, *Transitioning to Sustainable and Resilient Fisheries*.

In this annex, a generic version of the methodology used in the analysis of agricultural systems is provided. Commentary on its application and the lessons learned from this study are given. The ISU recognises that this methodology has many implications and needs further development. Its application is also constrained by the limited availability of data in certain countries, especially on environmental impacts. Nevertheless, it is hoped that this methodology could be one input into the development of the sort of analytical tool that policymakers need to assess the costs and benefits of food production systems.

Summary of the approach:

The methodology has four main steps. 1) Assessing the economic productivity of the system at the farm gate; 2) assessing the value of the environmental impacts of the system; 3) assessing the social impacts of the system and 4) examining the vulnerability of the system to exogenous shocks.

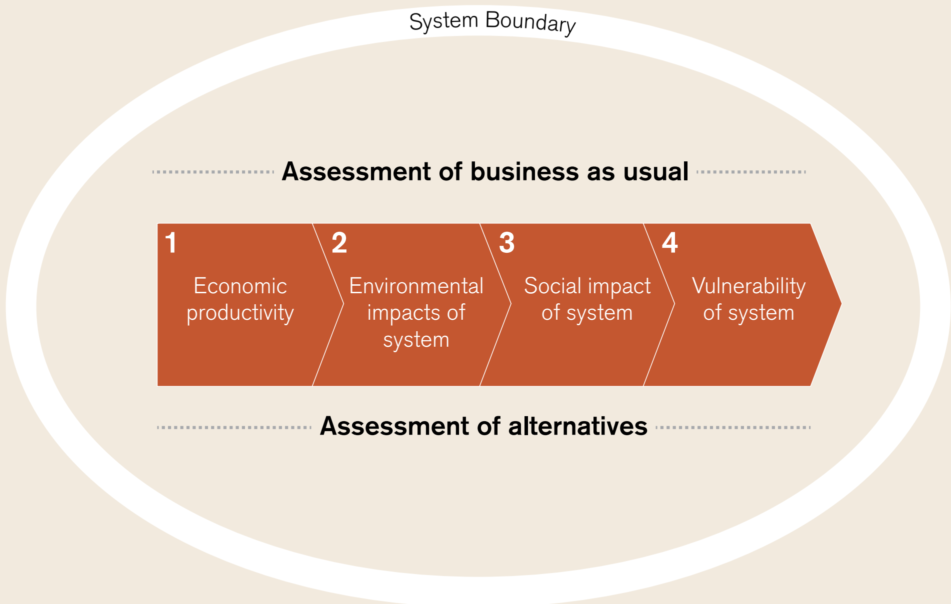
Before the methodology can be applied, the system boundary for analysis should be determined. This limits the scope of the analysis but allows practicable measurements of often-complex systems to be made. In this study, the system boundary was drawn at the farm gate (or wharf) and encapsulated all of the functions of the system associated with the production of food prior to that point.

Application of the approach in this study

1 The economic productivity of the system

The first step was to determine the economic productivity of the system. This was done by subtracting the direct costs of production born by the farmer and the cost of production born by society from the revenues received at the farm gate, or the equivalent market value if not sold. In calculation, the output revenue was a function of the market price of the food or

Summary of the approach



commodity produced multiplied by the quantity produced, using a five-year rolling average, which lessened the impact of short-term price volatility. Direct costs were made up of the total cost of inputs and factor payments. These included the costs of seeds, fertilisers, agro-chemicals, pesticides, fungicides and rent for land, wages for labour, and capital costs. When the cost of production was subtracted from the output revenues, the private profit of the system was given. Finally, subsidies and taxes as applied to the system were subtracted to reveal the full economic profit (or loss) to society. Subsidies and taxes are those levied on producers and consumers including production subsidies and taxes and were determined by literature review. Taxes, tariffs and subsidies on inputs and fuel were determined by comparing the price that farmers paid for inputs and fuel with their global market price.

The researchers found that economic productivity was the most readily measureable of all of the areas of analysis. For most cases, variables were already valued in monetary terms ($) and their use recorded by stakeholders throughout the system.

2 The environmental impact of the system

Environmental impacts include both the environmental "externalities" and the environmental "emternalities" of the production system. Externalities are the impacts that a production system has outside of itself on the ecosystem services that society relies on. Emternalities are the natural resources on which the production system relies upon for its own functioning.

This methodology considered the multiple externalities and emternalities of the food production system including the value of air pollution; water pollution; greenhouse gas emissions, water resource depletion, natural provision of water regulating services, soil degradation and the loss of biodiversity. Other types of environmental impacts that might be considered concern resource availability (mineral, land and fossil fuels). These were left out of the environmental impacts analysis as they are already valued as input prices in the economic productivity analysis. In each case, an attempt was made to quantify the environmental impacts and then to value them in US dollar terms.

Each category of environmental impact is examined as follows:

2.1 Air pollution

The cost of air pollution was calculated as the sum of input-associated air pollution and production-associated air pollution. Input-associated air pollution is the value of human health impacts caused by the production of agricultural input chemicals, such as nitrogen fertilisers. Production-associated air pollution is the value of human health impacts resulting from agricultural activities, such as the actual application of pesticides.

It should be noted that the costs associated with the health (or other impacts) of air pollution are not regularly or consistently measured across countries or in the life-cycle of the production of the various inputs to agricultural (or fishery) systems. Typically, these are specific to individual agricultural systems. Where local studies were available, this data was used in the case studies. Where robust local cost data was not available, the researchers used surrogate values scaled from other studies – recognising that this approach is subject to much error. This is an area that would benefit from further development in future work.

2.2 Water pollution

Analogous to air pollution, the value of water pollution was derived from local studies and calculated as the total of the cost of cleaning drinking water, the cost of health impacts, and the cost of damage to other systems. Here, the cost of cleaning drinking water was the costs of treating water that had been contaminated by chemical run-off and sedimentation. The cost of health impacts is the cost of treating illness resulting from water pollution that cannot be treated. The cost of damage to other systems is the economic losses suffered by other functional systems, such as fisheries, resulting from the pollution of water courses or oceans.

2.3 Greenhouse gas (GHG) emissions

The costs of greenhouse gas emissions includes both those arising directly from food production, as far as the farm gate, and those resulting indirectly from production, mainly via land use change. In this study, the cost of emissions from production was calculated as the area of land under production multiplied by the areal emission intensity of that land and the unit cost of emissions to society.

The cost of emissions from land-use change was calculated as the areal extent of land use change multiplied by the land use conversion emission intensity and the unit cost of emissions following the methodology set out by the IPCC in their AFOLU emissions calculation framework. In this study, the production area is the number of hectares (or heads of livestock) harvested. The areal emissions intensity is the sum of emissions associated with (1) production and use of chemical inputs (tCO_2e ha-1), (2) irrigation pump operation (tCO_2e ha-1) and (3) on farm fuel use (tCO_2e ha-1). The extent of land use change is the area of land converted to a new type of agriculture, and was assumed to be zero in steady-state agriculture unless a slash and burn practice was adopted. Land use conversion emission intensity was the total of above- and below-ground biomass carbon lost per unit area (t CO_2e ha-1).

In this study, the *unit cost of emissions* was assumed to be US$29 tCO_2e-1. This is derived from a study that calculated the average value (the mean) of 232 separate published estimates of the social cost of carbon. The "social cost of carbon" is defined as the net present value of the incremental damage due to a small increase in carbon dioxide emissions.

The ISU recognises that this analysis is particularly sensitive to the value placed upon carbon. Alternative assumptions for the social cost of carbon that exist include the Stern

Review cost of US$86; Tol's median cost estimate of US$8 per tonne of CO_2e; the McKinsey marginal abatement cost estimate of ~US$70 and the related marginal abatement cost for agriculture; and the market price of carbon, currently €15 tCO_2e-1 in the EU.

2.4 Water depletion

The value of water resource depletion was estimated in one of two ways: as either a) the replacement cost of water consumed by the agricultural sector; or b) the opportunity cost of water basin output forgone due to agricultural activity. This analysis was undertaken at the basin level, and if, data allowed the choice of either approach, the lower value was adopted.

2.5 Soil degradation

Soil degradation accounts for the loss of soil health caused by the system and is analogous to water resource depletion. In this study, the researchers calculated the cost of soil degradation as the economic value of the output that was lost from a farming system due to degradation occurring. The assessment of whether soil degradation had occurred was taken from the global GLASOD and USDA soil inventories and the value of output loss identified from country specific literature. When no such identification was possible, a first approximation was to compare the output of areas with the system that have different rates of soil degradation.

2.6 Loss of biodiversity

There is little existing consensus on how to value biodiversity, with even the most recent attempts, such as those taken in The Economics of Ecosystems and Biodiversity study (TEEB), unable to adopt a consistent means of valuation. This study adopted an adapted version of the one set out by TEEB and measured biodiversity at the level of the biome. Here, biodiversity was assumed to include the value provided by the presence of individual species and the service provided by their interaction (such as pollination by honeybees). It excluded ecosystem services that were captured elsewhere in the methodology such as net carbon sequestration.

The value of use and existence of species present represented the direct value of species to humans and was determined by either a) a market value or b) contingency valuation. The value of biological prospecting reflected the value that the commercial sector was willing to pay to access a species and was determined by markets or the industry, and the value of ecosystem services included the services that have agricultural significance that risk being lost due to changes in production. This latter category is often difficult to value and presently relies on the availability of specific local studies that quantify and value ecosystem services.

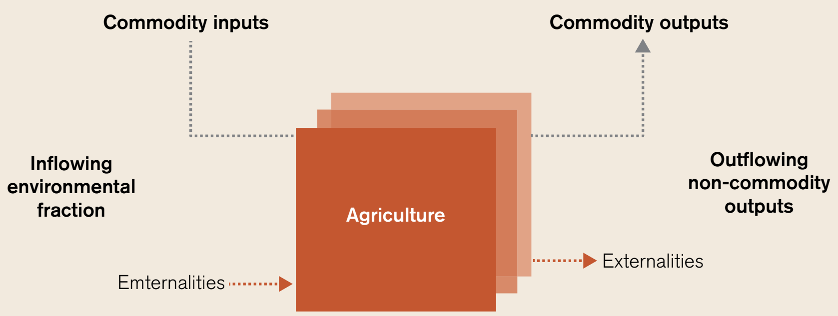
Application of the methdology showed that environmental impacts data are rarely collected in a consistent or systematic way globally. In this study, data was derived from local studies and extrapolated to the country scale for air pollution, water pollution and water resource depletion and from global studies scaled with regional information for soil degradation and loss of biodiversity. Where local literature or information was not available, surrogates were used or data from other case studies were adjusted and used as assumed values.

Environmental externalities and emternalities

When we think about the environmental issues associated with food production, we typically think in terms of its environmental consequences. These include soil degradation, greenhouse gas emissions and water pollution to name but a few. The cost of these consequences is rarely born by their producer or by commercial markets but rather by society as a whole – often those that didn't agree to the action that caused the cost in the first place. In economic terms, these costs or benefits are referred to as externalities.

Emternalities are the figurative counterpart to economic externalities. They represent the input or service that the environment provides to food production but that are not captured within commercial markets. For example the role that biodiversity plays in improving soil condition and pollinating plants.

Emternalities versus externalities in agricultural production.



Source: Pillet et al., (2001)

3 The social impact of the production system

The range of positive and negative social impacts associated with agricultural and fishery systems reflects the diversity of the societies that they are situated within. Although some aspects of these can be quantified, it is difficult to monetise many of them and often relies on making a subjective value judgement. In some cases, it is very difficult to quantify any of the social functions of the system at all. Further, it is not always possible to place a system boundary around the social functions of individual food production systems - it may be better to look at a national or regional food system.

To this end, it is probably not desirable to try to place a monetary value on the social impacts of food production systems, as was attempted for economic and environmental impacts. Instead, the researchers identified some indicators of the social performance of agriculture that might be measured (although not valued). This was supplemented by qualitative analysis of some of the major issues associated with agricultural systems identified in the literature. The following were considered:

- The contribution famers make to food security indicating the extent to which local agriculture provides a food surplus. (No attempt was made to develop proxies for food access and utilisation.)
- An acceptable or favourable farming income when compared to the national average per capita income.
- Financial stress of farmers as measured by the debt to income ratio of the farmer or fisher. (Ideally this metric would be replaced by one considering how many producers are in an unsustainable debt position.)
- The working condition for farmers as examined by review of local studies.

However, the ISU recognises that these are extremely limited and believes that further work is needed on the evaluation of the social aspects of agriculture. As discussed above, it is not yet possible to place robust monetary values on the social functionality of food systems. One alternative way in which the system might still be measured is by scoring its social attributes relative to other national and global averages.

4 The vulnerability of the system

Vulnerability refers to the sensitivity of the production system to changing economic and ecological conditions, including both gradual changes and shocks that might occur on both its supply (input) or demand (output) sides. Thus, a vulnerability analysis should account for a) the likelihood of a shock happening and b) the current sensitivity of the system to changes in the flow of an input or output variable.

In this study, some preliminary analysis of the vulnerability of the system was conducted. This was static and indicative of what might be examined in the future. Vulnerability to shocks in energy and input prices, soil degradation, water resource depletion, pests and disease, biodiviersity and ecosystem functionality loss and climate change and variability were considered. It was only possible to quantify the current status of inputs and outputs local to the system. Further, it was not possible to assign any likelihood or probability of a shock occurring. As with social impacts, no monetary value was placed on the vulnerability of the system.

The ISU recognises that understanding the full vulnerability of these systems would require a more sophisticated, scenario-based, sensitivity analysis. Research carried out by the Resilience Alliance indicates that the following steps should be taken: first, developing a conceptual model of the food system that takes into account the key variables, how they interact and how they affect outputs; second, identifying the potential critical thresholds of the variables and assessing the likelihood of these thresholds being crossed; third, identifying management or governance changes that can prevent these thresholds being crossed. Developing practical policymaker tools for assessing and strengthening resilience is highlighted as a priority area for future work. [Source: Resilience Alliance, Resilient Assessment Handbook]

5 Calculating net value, performance and vulnerability

Bringing the steps of the analysis together, the net value of the system is calculated as the value of produce at the farm gate over a five-year rolling period, net of direct monetary costs and quantifiable non-monetary costs (the cost of environmental pollution and natural resource depletion in the majority of instances). The result gives the value to society of the production system in economic and environmental terms.

It is then necessary to assess the performance of the system in terms of social costs and benefits, and resilience to risks and shocks. This is not a matter of monetary values, but rather qualitative assessment against social and political objectives combined with an analysis of risk.

6 Limitations of the methodology

The methodology's limitations include some that are intrinsic to the methodology and others that arise from the quality and nature of the data available to apply it to. Three main limitations arise from design choices in the methodology and the time and resources available to the researchers developing it. Further research is required to overcome some of these limitations.

Firstly, the methodology is primarily static, not dynamic. It aims to be comprehensive and cover the main dimensions of a food production system, but does not in general take into account how the parameters of these systems, agricultural technology, or resource allocation may change over time, with the exception of climate change (which has been modelled extensively). Further work should consider applying the methodology to forecasts of agricultural systems in 2030 or 2050, particularly to test resilience.

Secondly, it is not yet possible to quantify and value all of the dimensions examined in the methodology to the same extent. Application to the case studies showed that reliable and comparable data on the environmental dimensions is more difficult to obtain and that quantifying and valuing social impacts is fraught with uncertainty and issues of scope.

Thirdly, the number of indicators considered across each dimension is not exhaustive. Due to resource constraints, there were certain environmental impacts that the methodology did not look at. These included the value of the depletion of finite resources such as fossil fuels and phosphates and the water regulation services provided by landscapes – for example flooding control.

A final word of caution should be put forward. The results of applying this methodology were only as good as the data that it employed. In the cases prepared for this study, local data was sought for indicators but where such data did not exists, surrogates, proxies or extrapolations were used. There may be considerable uncertainty in each source of data and as yet, this has not been quantified.

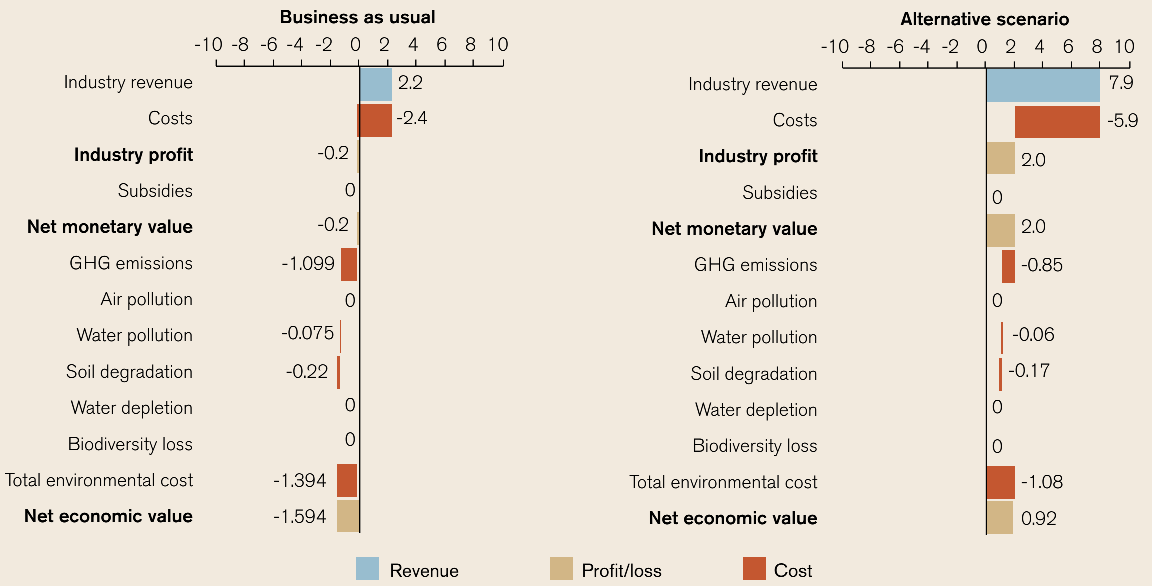
Looking forward, the ISU hopes that the methodology can be adopted and developed to address some of those limitations. A useful first step would be in exploring more dynamic ways to assess the resilience of the system over future time-based scenarios. Further the methodology might usefully be applied to other aspects of the food supply chain, such as food processing and distribution, or indeed to the food supply chain in its entirety. Also, whilst to date the methodology has been applied to individual commodity production systems at the national level, it could equally be applied at the farm, regional, national or international scales.

ANNEX B

Summary of case study results

Ethiopia smallholder staple crop farming		
	Business as usual	**A more sustainable alternative**
System description	Smallholder farming in fertile highlands (excludes pastoral and marginal farming zones). A subsistence system that combines production of five staple crops (maize, teff, sorghum, wheat and barley) and accounts for 43% of domestic GDP. The system is characterised by use of family labour. Historically, it has been plagued by productivity shocks for multiple reasons. Ethiopia has one of the largest dedicated public sector budgets for the agricultural sector when measured as a percentage of total spend.	A three-step approach to raising smallholder through higher yields and diversification: (1) improving yield per harvest through productivity packages which combine improved seeds, inputs and knowledge on soil preparation (80% of land); (2) increasing harvests through irrigation programs (10% of land) and (3) diversifying crop production by introducing vegetables, cash crops and/or livestock (80%).
Economic performance	The subsistence system is not a profitable form of crop production. Many farmers barely break even. However, subsistence farming remains the cheapest form of food for many of Ethiopia's rural poor, following food aid. Yields are particularly low; often less than half of what field trials have been shown to provide which can largely be attributed to poor seed choice, limited fertiliser usage, lack of irrigation and limited access to markets.	Implementing a combined programme could cost an additional $3.1 billion in annual investments (from the current $2.8 billion) if applied to all 11 million smallholder families. However, when applied in high potential areas, this could lead to yield improvement of 100-130% and dramatically improve food security. Irrigation could lead to a further ~20% improvement in yield through more frequent harvests in semi-arid areas.
Environmental impacts	Soil degradation and the presence of livestock cause some GHGs. Rapid soil erosion is also leading to siltation of rivers, which has an impact on the performance of hydroelectric power stations and ecologically important wetlands. Poor non-indigenous agricultural practices have led to significant soil degradation. The problem is further exacerbated by the continued expansion of agriculture to marginal lands on hilly areas, which are prone to erosion without proper land preparation.	Some reduction in GHGs comes from the decrease in total agricultural area tilled for staple crops because of improved yields. The cost of soil degradation as a proportion of the value of production falls because of better soil management practices.
Social impacts	Smallholder farmers produce few excess staples for the market and on average do not create enough food to meet daily sustenance requirements. Even improved current levels of production imply undernourishment. While farmer indebtedness is low, this is due to lack of access to credit and studies have shown that farmers have few financial alternatives to deal with shocks.	Farmers in high potential areas produce significantly more calories per hectare than in the BAU, making them more food secure and allowing them to sell some of the excess staples and the vegetables for cash. However, it should be noted that the combined alternative system is more capital and input intensive and could result in a higher debt burden for farmers. Further, a certain amount of consolidation could cause some unemployment.
Vulnerability	The fertile Ethiopian highlands do not suffer from water shortages and have a low reliance on fertilisers. However, low soil resilience has historically been a problem and continues to be aggravated by poor agricultural practices and deforestation. Climate change may increase the likelihood of drought in some regions but the extent is currently unclear.	Diversification into cash crops will reduce the vulnerability of smallholder farmers as they will be able to both increase the nutritional quality of their diets while increasing their cash flow. However, increasing productivity through higher use of inputs will make the system more vulnerable to input price shocks.

Summary of value

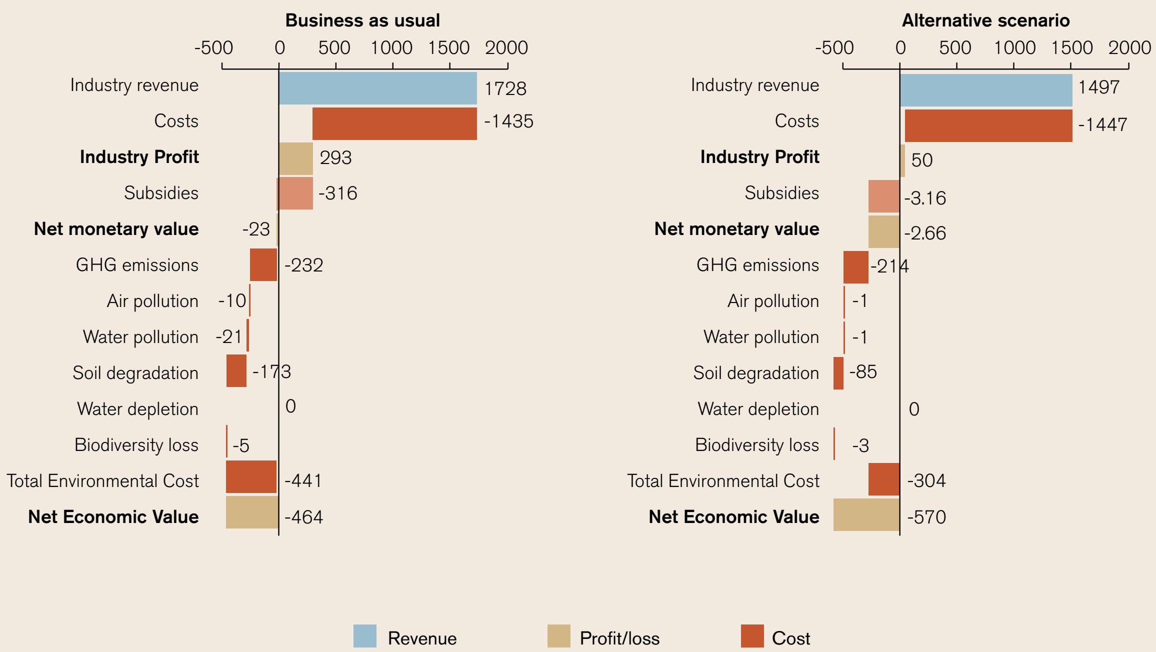


All figures in $US millions equivalent

UK farming system

	Business as usual	A more sustainable alternative
System description	The output of an average UK hectare of land is examined. This represents a mixed farming system that includes the production of the cereals wheat, barley and oilseed, vegetables including beans, potatoes, sugar beet and peas and dairy, poultry and meat products.	The alternative system is based on data from a University of Reading study which studied the implications if all agriculture in England and Wales went organic. (Uni. of Reading, England and Wales under organic agriculture, 2009). The output from an average hectare was modelled. This represented a mix of crops and livestock farmed using a 'mixed organic' approach.
Economic performance	UK agriculture is highly productive per unit area: conventional cereal farming in the UK has one of the highest yields in the world (>7 tonnes per hectare for wheat, 6 tonnes for barley), while the livestock sector means that the UK economy is relatively self-sufficient in meat and dairy products. These high yields are offset by the high social cost of subsidies, around 20% of all costs. The average farm relies on these to break even.	An average mixed organic farm earns approximately US$1,497 per hectare per year, reflecting the lower yields of crops grown organically and the shift towards less intensive livestock raising (fewer pigs and poultry, more grass-fed beef and lamb). Some of this decrease is offset by reduced costs, as fewer inputs and livestock feed are required.
Environmental impacts	Externalities are high in absolute terms, but are low relative to the value of output because of the high yield of UK cereal crops. Most of these externalities are GHG emissions and air pollution from fertilisers, pesticide, machinery and livestock. Natural resource depletion is now relatively low in the UK, thanks to low rates of irrigation and deep, fertile soils. However, 17% of arable land shows signs of erosion. Biodiversity is also declining, especially farmland bird species and pollinating species, thanks in part to intensive use of agri-chemicals.	Externalities are lower in the mixed organic farm, as chemical inputs are not used and increased soil organic matter leads to carbon sequestration. These gains are offset to some extent by increased methane emissions from livestock. Natural resource depletion related to physical soil erosion falls because more land is devoted to grassland with lower erosion rates. The organic farming system also retains, and in some instances improves, biodiversity.
Social impacts	Conventional cereal farming produces a high food surplus per worker. Good working conditions for farmers and high ownership of land also contribute to rural society indirectly. However, farmers' incomes are lower than the national average. Further agriculture only creates 0.5% of domestic GDP and the UK still imports 59% of food rendering it one the world's largest food importers.	Organic farming is more labour intensive, so the number of jobs (and wages earned) increases vis a vis conventional systems. Other social changes, such as changing non-farm employment or farm consolidation, have not been considered. Farm conditions are good because of high mechanisation and good working conditions. The quantity of food produced falls, and the type of food produced changes. This may have implications for food security without changes in usage or demand.
Vulnerability	High input use leaves the UK system exposed to input price shocks. However, the risk of crop disease is low and vulnerability to all other potential changes (soil, water, and climate change) is relatively low compared to other areas in the world.	Reduced reliance on fertilisers makes the mixed organic system less exposed to changes in input prices. However, the system does continue to be moderately vulnerable to water stress, soil depletion and climate change.

Summary of value

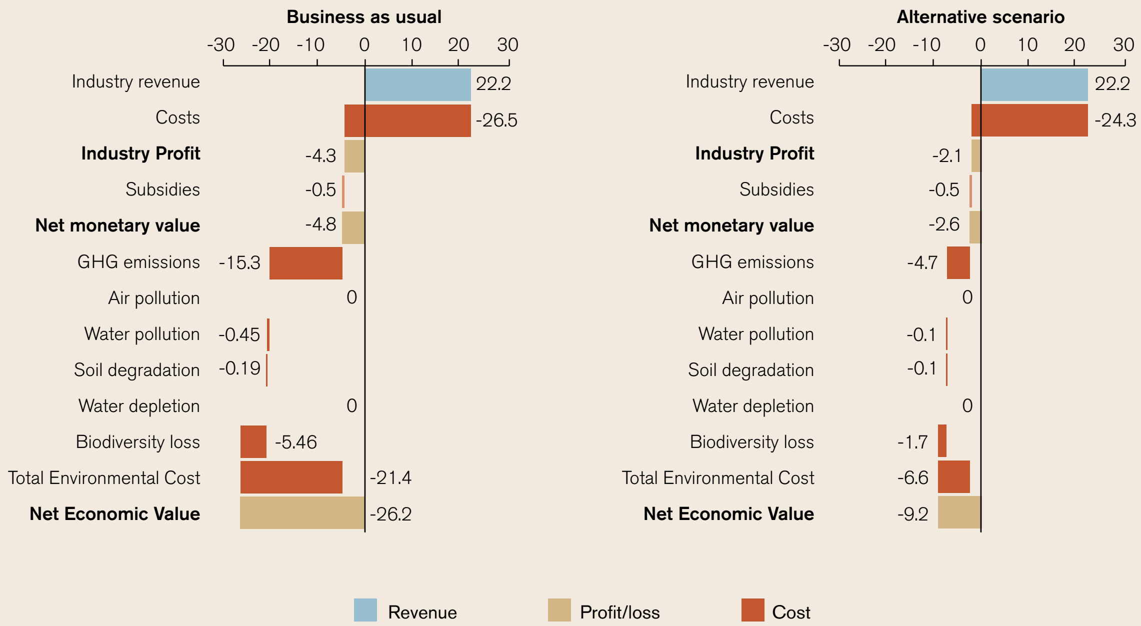


All figures in $US millions equivalent

Brazil beef production

	Business as usual	A more sustainable alternative
System description	An extensive production system encompassing over 200m head of cattle. Brazil is a cost-competitive producer on the global market and thus the world's largest beef exporter. Driven by rising global meat demand, the industry is trending towards a 50% increase in production within the next 10 years.	Intensification of cattle ranching on existing pastureland, with no new forest conversion. This relies on a combination of: (1) Improved forage, soil fertilisation and animal genetics; (2) implementation of silvopastoral techniques; (3) implementation of integrated crop and livestock systems.
Economic performance	Beef has generated the Brazilian economy in excess of US$22bn annually since 2004. Whilst a first view of industry profit shows a net loss, this is because the figures assume a land-rent which many producers may not actually pay, as illegally cleared land is acquired at almost zero cost. The result is profitability in production for certain farmers and for the majority of farmers, especially when foreign exchange conditions are favourable.	A shift to the combined alternative production scenario would cost ranchers in the short-term due to higher capital and operating expenditure. However, these measures would eventually pay for themselves, giving an estimated 8% IRR over 22 years. Funding from international schemes designed to reduce emissions from deforestation and degradation (known as REDD+) could help finance a transition.
Environmental impacts	Beef produces extremely high GHG emissions per tonne of food produced. These arise directly as methane from grazing cattle and indirectly via the carbon attributed to land use change (and clearance), particularly via tropical deforestation. Deforestation is contributing significant GHG emissions, soil degradation and loss of biodiversity in the Amazon region. However, evidence suggests that Brazil's rate of deforestation has dropped significantly in the last 5 years.	A combination of pasture and nutrient management would allow for higher stocking rates and a reduction in loss of pasture to degradation. In turn, pressure on pasture expansion and deforestation would be reduced, leading to lower associated GHG emissions and biodiversity costs. Further, intensification of cattle production on 40% of pasture land would free approximately 12 million ha for afforestation / reforestation projects.
Social impacts	Cattle ranchers in Brazil produce a large protein surplus for domestic consumption. However, farmer income is much less than the national average due to the fragmented nature of production and an inability to realise economies of scale. Further, the Brazilian government has found more than 25,000 workers in the beef production process working under slave-like conditions.	The alternative would lead to some limited job creation versus 'business as usual' via the establishment of monitoring and verification personnel in cattle, charcoal and soybean chains. Further, it is expected that rural communities would benefit from improved incomes in the long-term as investment in pasture management pays back.
Vulnerability	The extensive nature of Brazilian beef production makes the sector relatively resilient to input price and environmental shocks. In the near term, the industry is vulnerable to global exchange rates, which could impact export demand. In the longer term the industry could also be vulnerable to climate change, particularly if deforestation changes the rainfall regime in the Amazon.	System vulnerability would not be affected in the short to medium term, however in the longer term it is likely that its vulnerability to regional climate change and variability would be reduced if a successful net reduction in tropical deforestation was achieved.

Summary of value

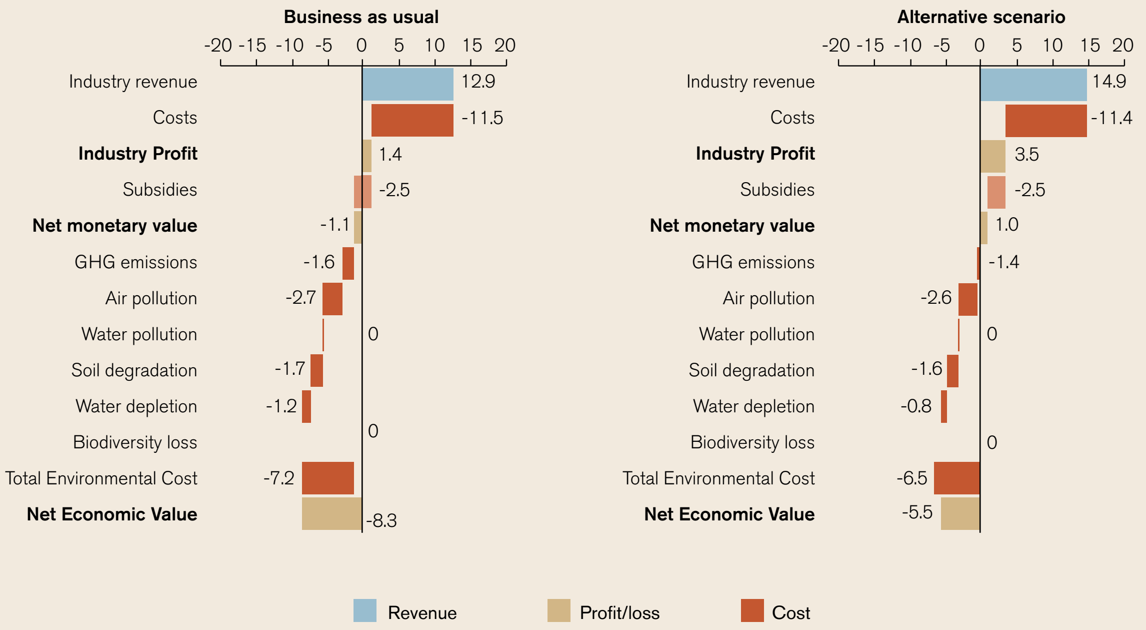


All figures in $US millions equivalent

India wheat production

	Business as usual	A more sustainable alternative
System description	Two production system are examined: (1) a high productivity intensive system in Punjab and Haryana, responsible for producing one third of India's wheat on little over one-fifth of its land. This has an average yield of 4.5 tonnes per hectare and (2) a low input, low irrigation and small-farm system producing 1.6-2.8 tonnes per hectare in regions across the rest of the country	Two alternatives systems are examined: (1) Altered agricultural practices to reduce dependence on fertilisers and groundwater in Punjab and Haryana. These included: optimising irrigation, improving soil fertility, reducing post-harvest losses, and leaving land fallow. (2) Elsewhere the focus was sustainable intensification to improve yields via improved agronomic methods and the reduction of post harvest losses.
Economic performance	Both systems are socially unprofitable once the opportunity costs of land and labour (usually family labour) and subsidies are taken into account. However in Punjab and Haryana, higher yields, enabled by higher levels of state government support, drives high private profitability. Yields and profitability are much lower elsewhere because of low use of tailored seed varieties, fewer inputs and reliance on rain-fed cultivation.	In both sets of alternatives, higher economic productivity was achieved due to higher yields with negligible increases to input costs. Where inputs were increased in alternative 2, overuse was eliminated via effective knowledge transfer leading to net economic gain. However, to increase production, total subsidies did increase in alternative 2.
Environmental impacts	GHGs per capita are the lowest in the world. Nonetheless, GHGs, air and water pollution are severe in Punjab and Haryana because of high fertiliser and agrochemical use. There are severe health impacts as a result of inappropriate pesticide use. Water depletion is the main concern in India. Around 75% of groundwater used in Punjab & Haryana is from overexploited aquifers, with slightly lower levels in other states. As there is almost no land-use change from wheat and estimates of biodiversity value in India are poor, loss of ecosystem functionality is not calculated.	Alternative 1 improved environmental performance through lower GHG emissions from rebalanced NPK manufacturing, natural nitrogen fixation and thus less reliance on N fertiliser and a decrease in land used for wheat. Further, groundwater use was reduced by 50%. Alternative 2 resulted in higher crop yields from better quality seeds, more input usage and more irrigation, but higher GHG emissions from these activities.
Social impacts	In Punjab and Haryana there is a high production surplus creating better farmer incomes than the national average. In other states there is low food surplus, low farmer incomes and high financial stress. Of particular concern is indebtedness as farmers put up collateral to purchase seeds and fertilisers and suffer poor working conditions.	Under both alternatives (1&2), economic productivity rose in both states leading to improved social impacts. There was a small decline in wheat production in Punjab & Haryana. This was more than offset by increased yield in the rest of India, which led to higher incomes, greater food surplus and less farmer indebtedness.
Vulnerability	Climate change could reduce yields in India by up to 40% by 2050 through higher temperatures and more frequent floods and droughts. Groundwater is being depleted rapidly. The soil used for growing wheat is already depleted and water shortages may worsen this state in the future. These factors combine to make the industry highly vulnerable to current and future shocks.	The system is less vulnerable because of decreased depletion of non-renewable groundwater reserves; more efficient use of inputs due to removal of production-linked subsidies; better soil management practices reducing soil erosion and loss of soil nutrients; and overall improved productivity.

Summary of value

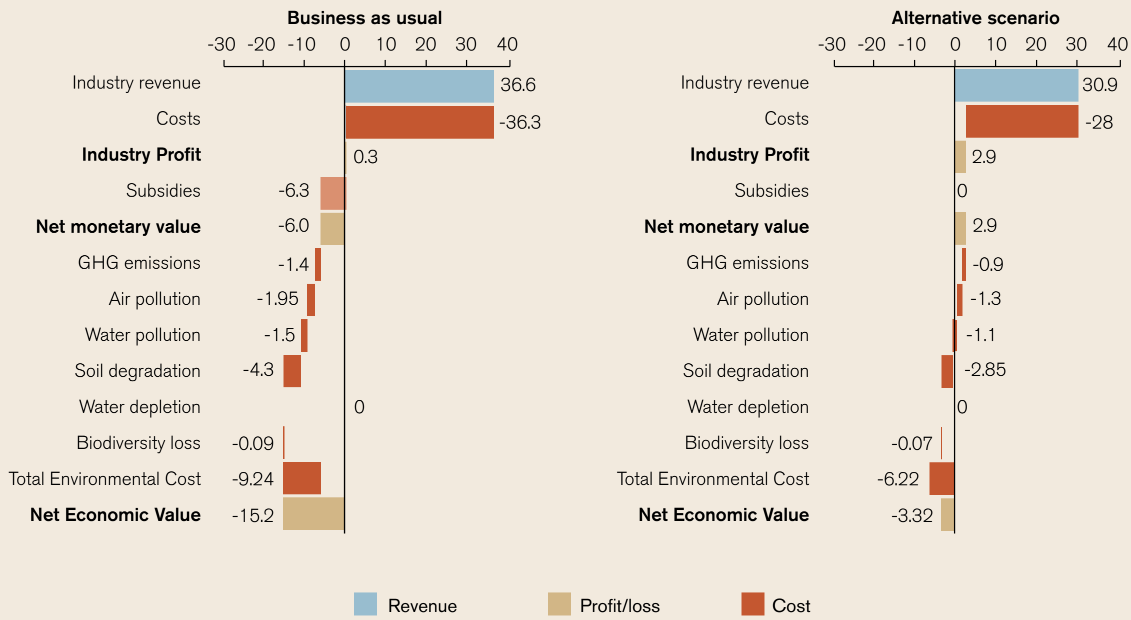


All figures in $US millions equivalent

USA corn

	Business as usual	A more sustainable alternative
System description	A highly intensive production system responsible for producing over 1/3rd of the calories consumed in the USA. The main output of production – corn starch – is used in multiple products including sweeteners and animal feed. The industry has experienced a recent transition with a major new revenue stream for its product – ethanol-based biofuels.	In this model, precision agriculture is adopted on 50% of the area planted to corn, which could increase output by 5-10% and reduce fertiliser use by 5-25% depending on the location Crop rotation is adopted for another 50% of the area, reducing corn production in those areas by ~1/3. Subsidies are cut to zero for all production reductions, leading to an increase in corn prices.
Economic performance	The corn production system is very high yielding and makes efficient use of land and inputs leading to large revenues at the farm gate. However, private profits were low during the period studied and heavy subsidies (estimated at ~15% of output) lower the net economic value.	The economic performance of corn improves due to improved yields obtained through precision agriculture and increased prices. Input costs are reduced through the use of improved agronomic practices and crop rotation.
Environmental impacts	Corn produces relatively low GHG emissions per tonne of food because of high yields, but total emissions are still substantial at 48 million tonnes of CO_2e. ~80% of emissions come from high use of inorganic fertiliser and subsequent denitrification. The Corn Belt region is largely water secure, with only 15% relying on irrigation. Soil erosion rate is high, at 10 tonnes of soil per ha per year. Biodiversity lost to corn production has low economic value.	GHG emissions, air pollution and water pollution fall as a result of the reduction in fertiliser use. The amount of soil degradation also falls by 25–50% as a result of greater cover cropping, rotation and precision agricultural practices that reduce soil disturbance.
Social impacts	Corn is a capital-intensive industry with very high production per farmer and farming incomes above average. Whilst its production currently employs ~350,000 farmers, industrial consolidation is reducing the number of jobs. Farmers produce large calorie surpluses, although much is used for animal feed and biofuels. Abundance and cheapness of corn may contribute to obesity and poor health outcomes in US society.	There are no substantial changes to social impact as defined in this analysis. The number of people employed in agriculture, or its contribution to US food security, does not change substantially. The small decrease in corn production could be part of a broader shift to healthier diets.
Vulnerability	Climate change could reduce yields in the corn-belt by up to 30% by 2050 through higher temperatures and more frequent floods and droughts. Corn has rebounded from climate and disease shocks in the past but its high dependence on mineral inputs and fossil fuels makes it vulnerable to input scarcity and price shocks.	Vulnerability falls slightly under the precisions system, as fewer inputs are used and more rotations lessens the exposure of the system to input price shocks. Decreased soil degradation will also increase long-run sustainability.

Summary of value

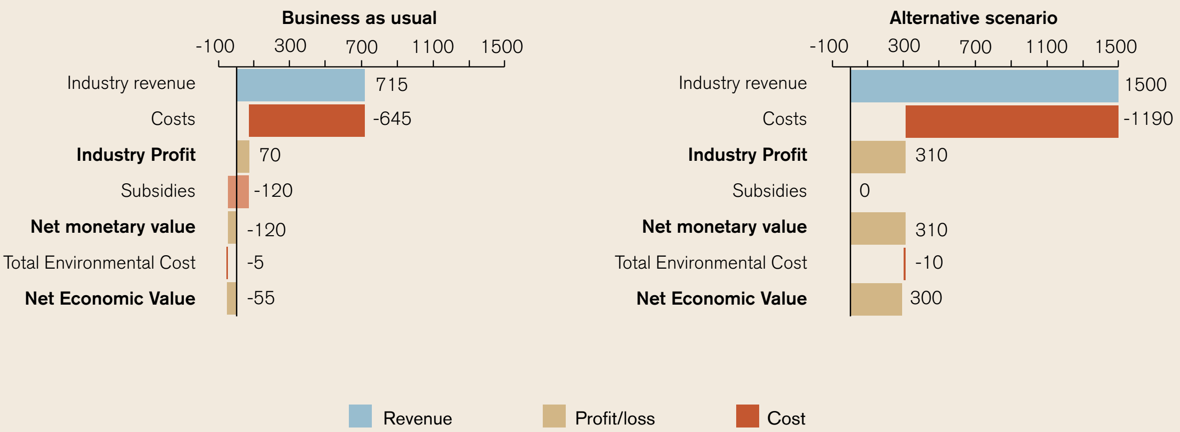


All figures in $US millions equivalent

Northeast Atlantic Bluefin tuna fishery

	Business as usual	A more sustainable alternative
System description	A small but high value fishery exploiting northern Bluefin tuna (Thunnus Thynnus), found in the waters of the Atlantic Ocean and Mediterranean Sea and considered critically endangered. Output is to a global market (luxury sector) with demand highest in Japan. The fleets are mainly from France, Spain and Italy.	To recover the fishery to a sustainable state, a number of measures would be needed. These could include the elimination of illegal, unreported and unregulated (IUU) fishing; removal of capacity-enhancing subsidies; a short-term reduction in fishing capacity; the effective implementation of gear restrictions, size and age limits and catch documentation; and the implementation of effective monitoring and enforcement.
Economic performance	The Bluefin tuna is a small but high-value fishery that is privately profitable, although it does receive significant subsidies from governments (c. 17% of revenues), resulting in combined input costs and subsidies which are greater than the value of industry output. The ratio of output value to input value in the current state of the Bluefin tuna fishery is around 0.95.	It is assumed that after stock recovery (with continuing appropriate size and age restrictions), annual catch could be increased to about 50,000 metric tonnes per year. The industry would be more profitable, create more employment, and be sustainable indefinitely, under an appropriate management regime. However, additional annual management costs of 5-10% of revenue may be required to maintain sustainable state.
Environmental impacts	Per-unit CO_2 emissions are higher than the average among global fisheries due to the long distances travelled by vessels. However, due to the high value of the tuna, this represents less than 1% of revenues. Systematic observation also show that bycatch levels in this long line fishery are high (c.34%) and include loggerhead turtles, swordfish and rays. Most importantly, Bluefin is being overfished by a factor of approximately 3 above a short-term sustainable rate. At current fishing rates the stock will be exhausted in 12 to 15 years.	Assessed CO_2 emissions increase as the total catch increases, although because of the reduction in IUU fishing they are likely to stay the same. Social cost as a share of total revenues would remain marginal. Bycatch is reduced through additional gear restrictions resulting in a drop to ~10%. The fishery would transition to a sustainable level of extraction at the Maximum Sustainable Yield (MSY).
Social impacts	The social impact of the Bluefin tuna fishery is minimal in terms of food security and employment because the fishery produces a small amount of high value food and employs few people (approximately 1% of the working population of the countries involved). However, the fishery has good working conditions and relatively high wage levels.	The social impact of a more sustainable alternative Bluefin tuna fishery would not change substantially, but the long-term change would be in the positive direction (higher wages, etc) – even if the impact is not big enough to make a difference on the scores. A larger and more sustainable stock could create 20-30% more jobs after recovery of the fishery to the MSY.
Vulnerability	The stock of Bluefin tuna is so severely overfished that it is vulnerable to collapse. Bluefin stocks in the East Atlantic and Mediterranean are between 19% and 53% of Sustainable Stock Biomass populations and are vulnerable to both continued overfishing and exogenous shocks such as ocean temperature increases.	Stocks would return to an MSY level reducing vulnerability to fish stock collapse.

Summary of value

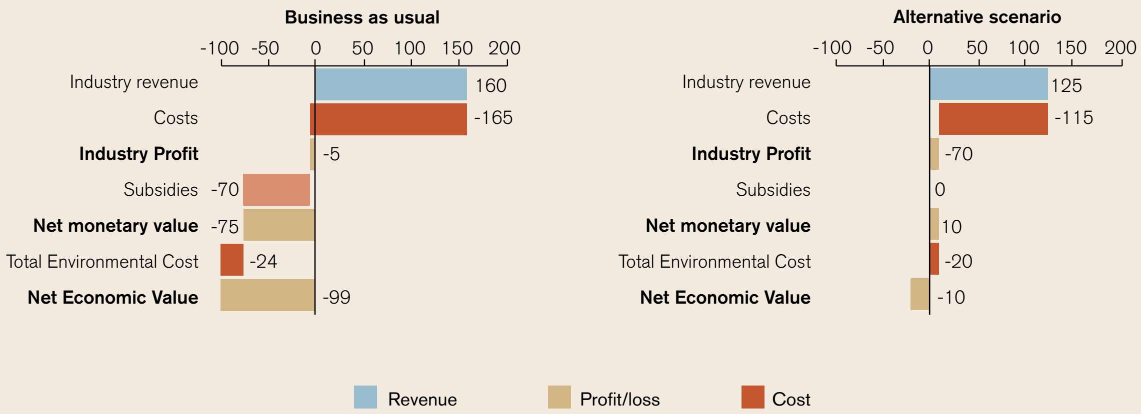


All figures in $US millions equivalent

Senegalese coastal fishery

	Business as usual	A more sustainable alternative
System description	A fishery that comprises both industrial and artisanal fleets. Historically, the artisanal fishers have sought Sardinella within the coastal zone (and now increasingly further out to sea) and the industrial fleet has fished higher-value species such as tuna, shrimp and hake for export. In theory the industrial fleet can only fish beyond 6 miles off the coast, but enforcement is weak.	The fishery is allowed to recover to MSY by reducing catch volumes by 25%. This is achieved by reducing fishing capacity, reducing quotas and improving enforcement. It is predicted that a 5% price increase would occur because fishers would be able to catch more valuable species. Further, after the transition phase it would be possible to remove subsidies and maintain a profitable fishery.
Economic performance	The fisheries employ 45,000 people and 140,000 in the processing industry. However, the Senegalese coastal fisheries are privately unprofitable. When including the value of government subsidies, combined input costs and subsidies are significantly greater than the value of industry output with the ratio of output value to input value plus subsidies in the current state approximately 0.68. The industrial fleet does provide approximately 30% of Senegal's foreign exchange revenue.	In a sustainable state, the total output of the fishery would decline, but input use would decline more, and subsidies would be eliminated. The result would be that the ratio of output value to input value plus subsidies would increase to around 1.11. Overall catch would remain lower than it is today at ~360,000 tonnes, down from 480,000 tonnes. However, taking into account price increases, private profits would increase to around US$10 million.
Environmental impacts	GHG emissions were estimated to be 1.7 metric tonnes per tonne of landed catch. It was not possible to quantify bycatch, but bycatch is estimated to be around 50% in the Senegalese coastal fishery. Furthermore, individual species are being overfished by 2.5 times the Maximum Sustainable Yield (MSY).	GHG emissions would be proportional to catch. A reduction of 25% in the catch in the alternative scenario would see a similar reduction in emissions to just over 600,000 metric tonnes. Further, stocks would stabilise at MSY.
Social impacts	The coastal fishery employs c. 42,000 artisanal fishers and the industrial fleet employs another 2,500 people, with an implied salary of around $5,000 per year. Artisanal fleet wages are low, child labour makes up 15-30% of vessel crews and conditions are described as 'difficult and precarious'. The total wage bill for both fleets is estimated to be approximately US$50 million per annum. The fishery provides a very important source of protein for Senegal – 61% of produce is consumed domestically.	Employment in fisheries would fall to around 28,000 people in total. However, salaries would increase, so the total wage bill would only decline to US$40 million. Although the reduction in employment is substantial, under business as usual the fishery is vulnerable to complete collapse and it does not provide maximum food security benefits. The total value to society of the Senegalese mixed coastal fishery under a sustainable state would be in the region of US$80 million; markedly different from the business as usual scenario of US$ 49 million.
Vulnerability	Senegalese fish stocks are overfished, with fishing capacity 2.5 times that warranted by the MSY. The fishery is on a path to collapse and also acutely vulnerable to exogenous shocks such as ocean acidification.	Stock spawning biomass (SSB) would recover to such a level so as to keep the stock at MSY, and the fishery's resilience to exogenous shocks is significantly increased.

Summary of value

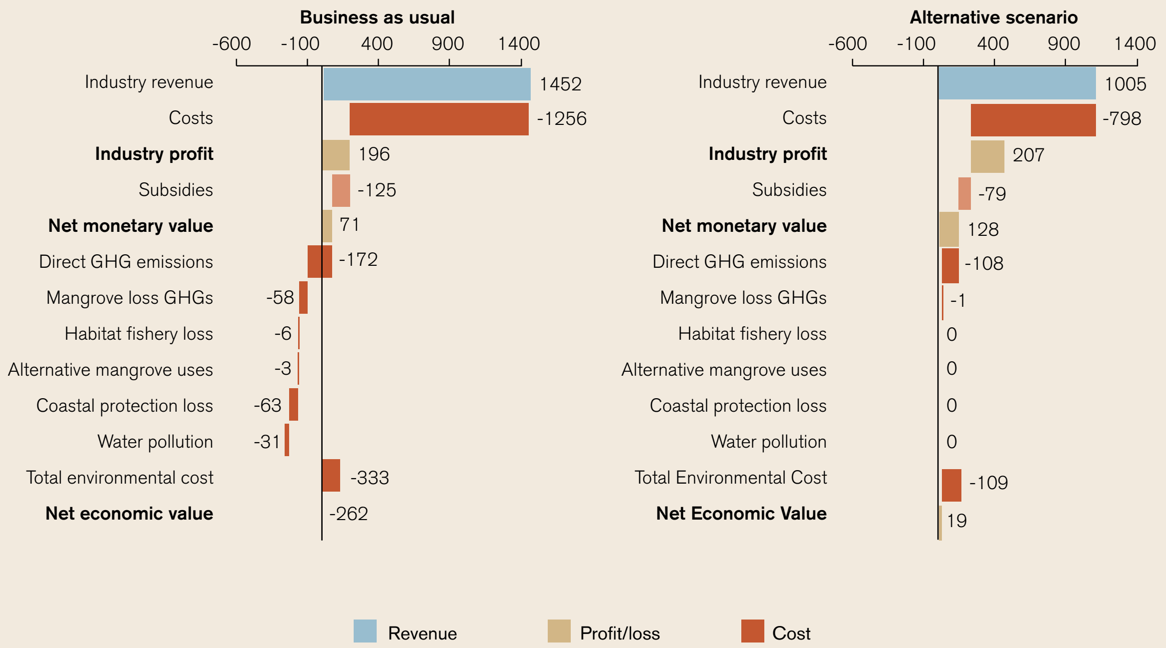


All figures in $US millions equivalent

Thailand shrimp farming

	Business as usual	A more sustainable alternative
System description	A rapidly growing export driven industry with a total annual production of around 570,000 tonnes (~9% of the world's shrimp). Intensive shrimp farming is replacing traditional farming and makes use of artificial inputs and substantial amounts of feed. The system produces intensive yields of c.15 tonnes per ha as opposed to 200kg per ha-.	Shrimp farms become less intensive. The following measures might be used: new shrimp farms are located above the tidal zone (on supra-tidal land); farmers are required to treat effluent from the shrimp ponds; farms bear the fixed costs of building storage ponds; farms lower the intensity of production to an average of 4.5 tonnes per ha. Further, the government reallocates subsidies to support better management practices, including the use of local seed.
Economic performance	Shrimp farming is attractive for Thai farmers because of the relatively high value of shrimp exports compared to other farming products. Subsidies are relatively low in comparison to total industry revenue. Production has increased so much, the cost per Kg has halved since 1991. However, the ratio of output value to input value in the current state of shrimp farming is only ~1.05.	Thai shrimp would gain a 10% price premium as guaranteed sustainably-farmed seafood commands a price premium. Lower costs per unit production and higher prices increase the economic productivity of the industry, even when accounting for additional water management costs. The ratio of output value to input value rises to ~1.15.
Environmental impacts	Shrimp farming produces significant environmental externalities including the loss of coastal protection against storm damage and water pollution from farm effluents. Further, the loss of carbon storage from mangrove deforestation and direct carbon emissions from fuel used equate to 22% of total industry revenue. Further, soil salination due to seepage from shrimp farms to neighbouring land and the potential for disease outbreaks that spread to wild shrimp populations and thereby deplete local fish stocks are a risk.	Environmental externalities are reduced. The cost of direct carbon emissions from production would represent around ~11% of production value. All environmental externalities and natural depletion costs related to the loss of mangroves and the cost of water pollution would also become zero. (The responsibility for sustainability is internalised by the industry).
Social impacts	25% of production is consumed domestically so shrimp farming has a relatively minimal impact on food security. However, wages are good for farmers: the average return to farmers is estimated to be approximately $5,800 p.a., which was more than ten times the Thai average wage in 2008.	In the sustainable state, the average return to farmers would increase to ~$6,000 p.a. However, with the total volume of production decreasing, the number of farm workers would likely decrease.
Vulnerability	Shrimp farming is vulnerable to disease and vulnerable to storm damage – the latter made worse by mangrove clearance. It can also be a 'hit and run' industry, with farms eventually becoming unusable and left abandoned. Rising sea levels and a reduction in the availability of new land for farms will also affect the future of the industry.	System vulnerability decreases because the shrimp farming intensity decreases to 4.5 tonnes fish per hectare. Further <25% of farms are on intertidal land, so not as vulnerable to storm damage. The life expectancy doubles to 15 years.

Summary of value



All figures in $US millions equivalent

ANNEX C

Other examples of sustainable and resilient systems

Table 1: Agriculture

	Brief description	Location	Yield or income increase (if data available)	Risks addressed	
				Energy and inputs	Land and soils
AFRICA					
1	Zai planting pits for better productivity	Sahel, Burkina Faso	400%		√
2	Conservation agriculture	Kenya & Tanzania	200%	√	√
3	Agro-forestry using Faidherbia trees	Subsaharan Africa	6-280%	√	√
4	Agro-forestry using Ngitili tradition	Tanzania	na	√	√
5	Push-pull technology for pest management	Eastern Africa	200-350%x		
6	Weather information systems for farmers	Mali	80%	√	
7	Breeding traditional rice breeds for disease protection	Madagascar	na	x	√
8	Rainwater harvesting using trapezoidal ponds	Rwanda	na		√
9	Better food trade regulations	Zambia	na		
10	Wastewater treatment for irrigation	W.Africa	na		
11	Addressing post-harvest loss through grain storage bags	Subsaharan Africa	na	√	
12	Improving soil fertility with livestock	Ethiopia	na	√	√
13	Revival and extension of veg on small beds	Kenya & Tanzania	na	√	
14	Sustainable oyster harvesting through community management	The Gambia	na		
ASIA					
15	Storage silos for reducing post harvest loss	Afganistan	na		
16	Alternate Wetting & Drying for rice irrigation	Philippines	40%		
17	Rice-duck integrated production systems	Bangladesh	50-60%	√	
18	Zero-till technology in Indo-Gangetic Plain	India	5-7%		√
19	Organic tea and coffee for export	Nepal	na	√	x
20	Jatropha for decentralised energy provision	Cambodia	na	√	√
21	Rural enterprise increasing productivity away from state control	Uzbekistan		√	√
22	Emergency Irrigation Rehabilitation Project	Afganistan			
23	Restoration of Loess Plateau through land-use planning	China	na		√
24	Drip irrigation technology for banana plantations	India	30-35%		
25	Integrated fish-rice systems	Bangladesh	8-15%	√	
26	Simple technologies for urban gray-water irrigation	Jordan	na		
27	Sustainable Alpine rangeland management for degraded pasture on the Tibetan Plateau	China	na		√
28	Integrated vegetable, pond and livestock system	Vietnam	300-500%	√	√
SOUTH AMERICA					
29	Zero-till in Argentina for Soybean production	Argentina	na		√
30	Urban agriculture for food security	Havana, Cuba	na	√	
31	Drip irrigation technology for water and nutrients	Patos de Minas, Brazil	40%	√	

Risks addressed					
Water	Pests and diseases	Biodiversity and ecosystem functionality	Climate change	Poverty, inequality and underdevelopment	Source
√			√	√	IFPRI, 2009. Millions Fed.
			√	√	FAO, 2006
			√	√	World Agroforestry Centre, na
		√		√	World Agroforestry Centre, 2010
	√	√	√	√	De Schutter, 2010
			√	√	Moorhead, 2009
√	√			√	Worldwatch Institute, 2011
√	√		√	√	Worldwatch Institute, 2011
				√	Worldwatch Institute, 2011
√				√	Worldwatch Institute, 2011
				√	Worldwatch Institute, 2011
				√	Worldwatch Institute, 2011
	√		√	√	Worldwatch Institute, 2011
		√	√	√	Worldwatch Institute, 2011
				√	FAO, 2010
√				√	IRRI, 2008
	√			√	Hossein et al, na
√			√	√	DFID, 2010
				√	Winrock International, 2009
			√	√	Utz, 2011
√				√	World Bank, 2010
√					FAO, 2011
		√			Liu, 2010
√					Jains Associates, 2011
√	√	√		√	Ahmed & Garnett, 2011
√			√		Worldwatch Institute, 2011
		√			agriculturebridge.org, 2001
√				√	FAO, 2001
√					IFPRI, 2009
		√		√	sustainablecities.dk, 2011
√					Unilever, 2011

* The red ticks represent the primary risk addressed in the case study, as identified by the literature, and the black ticks represent additional benefits

** 'na' refers to the fact that no data was available in the literature

Table 1 cont.

	Brief description	Location	Yield or income increase (if data available)	Risks addressed: Energy and inputs	Risks addressed: Land and soils
32	Sustainable agriculture production system for food and health security	Belo Horizonte, Brazil	na	√	√
33	Improved potato yields from combining new crop varities with traditional methods	Bolivia	150-275%		√
34	Organic coffee for Indian communities	Mexico	30-5%	√	√
35	Alley cropping as an alternative to slash and burn in the Amazon rainforest	Honduras	na	√	√
NORTH AMERICA					
36	Using disposable 'Peepoo' bags for converting human waste to fertiliser	Haiti	na	√	√
37	Restoring degraded pasture through grass management and rotational grazing	USA	na	√	√
38	Integrated pest management for banana plantations	Hawaii	na	√	√
39	Conservation tillage supported by cover crops and rotations	USA	0%	√	√
40	A balanced no input crop and livestock system	USA	371%	√	√
41	Conservation tillage and precision irrigation in California	USA	na	√	√
AUSTRALASIA					
42	Retiring marginal land for biodiversity enhancement	New Zealand	na	√	√
43	Weed control by perennial pasture management for dairy farming	Australia	na	x	√
44	Perennial grasses, rotational pasture and trees for horse farm	Australia	na		√
45	Natural regeneration of shrub and canopy for water quality, biodiversity and buffer zones	New Zealand	na		
46	Centre-pivot irrigation for dairy pastures	Australia	100%	√	√
47	Open-hydroponics for fruit orchards	Australia	40%	√	
48	Sustainable grazing for dryland salinity for wool farmers	Australia	NA		√
EUROPE					
49	Veg processing wastewater treatment using natural reed beds	England	na	√	
50	Organic livestock for reduced chemical usage	Scotland	na	√	√
51	Scaling up of environmental technologies for eco-efficient agriculture (VERA project)	Denmark	na	√	
52	Agrosilvopastural system in Spanish dehesa landscape	Spain	na		√
53	Agricultural pollution control project in Romania	Romania	na	√	

Source:
Agriculturebridge (2011) Sustainable Alpine Range Management. http://www.agriculturebridge.org/
de Schutter, O. (2010) *Agroecology and the Right to Food.* UN Human Rights Council
DFID (2010) *Planting without plowing: zero-till wheat takes root*
FAO (2010) *Climate Smart Agriculture: Policies, Practices and Financing for Food Security, Adaptation and Mitigation*
FAO (2010) Conservation Agriculture for SARD and Food Security in Southern and Eastern Africa http://www.fao.org/ag/ca
FAO (2011) http://www.fao.org/nr/water/projects_afghanistan.html
Farm Trails (2011) *Rainton Farm.* http://www.farmtrails.org.uk/.
Hossain, S.T et al. *Effect of Integrated Rice-Duck Farming on Rice Yield, Farm Productivity and Rice Provisioning Ability of Farmers*
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IRRI (2008). *A Perfect Match* Rice Today
Jain Associates (2011) *High-Tech Banana Production Practices.* http://jisl.co.in/PDF/crop/hi-tech%20banana%20book.pdf . India
LandCare Australia (2011) http://www.landcareonline.com.au/?page_id=63
Landcare Trust NZ (2011) *Biodiversity case studies.* http://www.landcare.org.nz/regional-focus/lower-south-island/biodiversity-southland/
Liu (2010) Hope in a Changing Climate. http://www.hopeinachangingclimate.org/
Ministry of Agriculture, Denmark (2007) Danish solutions to global Environmentalchallengeshttp://ec.europa.eu/environment/etap/policy/pdfs/roadmaps/denmark_en.pdf
Moorhead, A. (2009) *Climate, Agriculture and Food Security: A Strategy for Change.* Alliance of the CGIAR centres
New American Farmer (2005) *Profiles of Agricultural Innovation.* 2nd edition. Sustainable Agriculture Network, Beltsville, MD

Risks addressed					
Water	Pests and diseases	Biodiversity and ecosystem functionality	Climate change	Poverty, inequality and underdevelopment	Source
√	√	√	√	√	World Future Council, 2009
		√		√	FAO, 2002
√					FAO, 2002
		√	√		Inga Foundation, 2009
					Worldwatch Institute, 2011
					radiancedairy.com, 2011
√	√	√			New American Farmer, 2005
√		√	√		New American Farmer, 2005
	√		√		New American Farmer, 2005
√			√		University of California, 2011
		√	√		Landcare Trust NZ, 2010
√	√	√	√		Landcare Australia, 2011
√	√	√			Landcare Australia, 2011
√		√			Landcare Trust NZ, 2010
√			√		Land and Water Australia, 2006
√					Land and Water Australia, 2006
					Land and Water Australia, 2004
√		√			Produceworld, 2011
		√			farmtrails.org.uk, 2001
			√		Danish Ministry of Environment, 2009
√		√			Olea & San Miguel-Ayanz, 2006
√		√			World Bank, 2011; World Bank, 2007

Olea & San Miguel-Ayanz, (2006).*The Spanish dehesa. A traditional Mediterranean silvopastoral system linking production and nature conservation*
ProduceWorld (2011) Home \ CSR \ *Environmental Stewardship - Our Commitment \ Environmental Stewardship* - Case Studies Online -http://www.produceworld.co.uk/csr/csr_environmental_stewardship-case_studies.asp
Pye-Smith, Charlie (2010) *Rural Revival in Tanzania: How agroforestry is helping farmers to restore the woodlands in Shinyanga Region* Nairobi. World Agroforestry Centre
Radiance Dairy (2011) http://www.radiancedairy.com/
Spielman & Pandya-Lorch (2009). Millions Fed. Proven Successes in Agricultural Development. IFPRI
Sustainable Cities (2011) *Havana: Feeding the city on urban agriculture* http://sustainablecities.dk/cases
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Utz, Veronica (2011) *Modern Energy Services for Modern Agriculture: A Review of Smallholder Farming in Developing Countries* GIZ-HERA Eschborn
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World Bank, 2011; *Romania Partnership Snapshot Programme.*
World Future Council (2009) *Celebrating the Belo Horizonte Food Security Programme.* http://www.worldfuturecouncil.org/fileadmin/user_upload/PDF/Future_Policy_Award_brochure.pdf
Worldwatch Institute (2011). *State of the World: Innovations that Nourish the Planet.* Earthscan. London
University of California (2011) *Conservation tillage as a means to sustainable agriculture* http://ucanr.org/blogs/CT/

Table 2: Fisheries

	Brief description	Location	Yield or income increase (if data available)	Science and data	Minimising bycatch
AFRICA					
1	Local knowledge and community management in Senegal's mixed fishery	Senegal	na	√	
2	Access controls and enforcement for the national fishery	Namibia	279.6%		
3	Multi-stakeholder participation in hake fishery management	South Africa	na		√
ASIA					
4	Rights and zoning system	China	na		
5	Cooperative area rights for clam fishery in Ben Tre province	Vietnam	49.2%		
SOUTH AMERICA					
6	Territorial user rights in Loco fishery	Chile	na		
NORTH AMERICA					
7	Access rights in the Pacific halibut fishery	USA	390%	√	
AUSTRALASIA					
8	Zoning in Great Barrier Reef Marine Park	Australia	na		
9	Bycatch reduction in northern prawn fishery	Australia	na		√
10	Gradual removal of subsidies and access rights	New Zealand	46.5%		
EUROPE					
11	Access rights in the cod fishery	Iceland	na		
12	Science and data collection for ecosystem-based management	International	na	√	
13	Conservation credits scheme for cod fishery	Scotland	na	√	√
14	Discard ban, area closures and enforcement	Norway	56.9%		√
15	Reduction of subsidies	Norway	na		
OCEANIA					
16	Utilising local knowledge and data for fishery management	Fiji	na	√	
INTERNATIONAL					
17	WWF Smartgear Competition	International	na		√
18	International Seafood Sustainability Foundation (ISSF)	International	na		

Spatial planning	Monitoring and enforcement	Stakeholder participation	Access rights	Perverse subsidies
√	√			
	√		√	
		√		
√			√	
			√	
			√	
√			√	
√				
				√
		√		
√	√	√		
				√
	√			

* The red ticks represent the primary risk addressed in the case study, as identified by the literature, and the black- ticks represent additional benefits

** 'na' refers to the fact that no data was available in the literature

N.B. These case studies are taken from another ISU consultative document: *Transitioning to Sustainable and Resilient Fisheries*, based on a report commissioned from MRAG Ltd. For further information on fisheries case studies see www.isu.org/reports

ANNEX D

Existing tools and methodologies

Tool/methodology/ framework	Organisation	Brief description	Source
EX-ACT	FAO	Carbon balance tool to appraise mitigation impact of newly proposed food security, agriculture policies and projects.	http://www.fao.org/tc/exact/en/
Resilience Assessment Workbook	Resilience Alliance	A tool to assess the resilience of social-ecological systems	http://www.resalliance.org/index.php/resilience_assessment
FAO SAFA	FAO	A framework that can be used at any level to provide a common understanding of what sustainability means at a practical level.	http://www.fao.org/fileadmin/user_upload/suistainability/docs/Background_Document_02.pdf
RISE (Response Inducing Sustainability Evaluation)	University of Applied Sciences Swiss College of Agriculture	An indicator-based method for holistic assessment of the sustainability of agricultural production at farm level: Energy and climate, Water use, Soil use, Biodiversity and plant protection, Nutrient flows, Animal welfare, Economic Viability, Quality of life, Working conditions	http://www.bats.ch/bats/events/2002-07_sinoswiss/pdf/3csinoswiss.pdf
Climate Change Impact Assessment Toolbox	FAO	An integrated methodology to assess climate change impacts on agriculture. It comprises of four software components: Global Climate Model, hydrological model, crop growth model, Computable General Equilibrium model	www.fao.org/nr/climpag/pub/FAO_WorldBank Study_CC_Morocco_2008.pdf
IDEA (Indicateurs de Durabilite des Exploitations Agricoles)	CEMAGREF	The tool is aimed at giving practical expression to the concept of sustainable farms. It is based on 41 indicators covering the three dimensions of sustainability.	http://www.idea.portea.fr/index.php?id=12
CFVAM (Vulnerability Analysis and Mapping)	WFP	A pre-intervention analysis/pre-crisis baseline study. An in depth picture of the food security situation and the vulnerability of households in a given country - normally conducted in countries subject to recurrent crises.	http://vam.wfp.org/
The Natural Step Framework	Natural Step	A comprehensive model for planning in complex systems - centres around the concepts of systems thinking, and backcasting from sustainability principles	http://www.naturalstep.org/en/applying-framework
The Five Capitals Model	Forum for the Future	Provides a basis for understanding sustainability in terms of the economic concept of wealth creation or 'capital' - any organisation will use five capitals to produce goods or services and a sustainable organisation will maintain or enhance these assets rather than deplete or degrade them. The five capitals are: natural, human, social, manufactured (physical), and financial.	http://www.forumforthefuture.org/projects/the-five-capitals
Public Goods Tool	Elm Farm Organic Research Centre	A tool to assess the sustainability of a farm in terms of carbon, water, soil, biodiversity etc. Data is collected by the farmer and put into the model which then produces a spiders web analysis of sustainability.	http://www.organicresearchcentre.com/
Tradeoff Analysis Model	Oregon State University	The Tradeoff Analysis is a highly complex policy decision support system designed to quantify tradeoffs between key sustainability indicators under alternative policy and technology scenarios. The results are presented in the form of tradeoff curves are based on the economic principle of opportunity cost. It draws on existing models for components of the agricultural system such as crop growth or carbon sequestration.	http://www.tradeoffs.nl/

Tool/methodology/ framework	Organisation	Brief description	Source
OSIRIS - (The Open Source Impacts of REDD Incentives Spreadsheet)	Conservation International	OSORIS is a decision support tool designed by the Collaborative Modeling Initiative on REDD Economics to support UNFCCC negotiations on REDD.	http://www.conservation.org/osiris/Pages/overview.aspx
ARIES (Artificial Intelligence for Ecosystem Services)	Conservation International	ARIES is a web-accessible technology used to map the ecosystem services of a particular region. ARIES creates maps which show the connections between the regions that provide ecosystem services and the regions that benefit from these provisions. It also identifies ecosystem service "sinks": areas where the resource benefits are being lost, such as in a polluted waterway.	http://www.conservation.org/FMG/Articles/Pages/mapping_natures_benefits_ARIES.aspx
CEDA EU-25	EU (DG Environment)	An example of an Environmentally Extended Input Output tool (EEIO). Aimed at policy makers these mainly combine top down economic data with bottom up LCA environmental impacts data. The CEDA model is designed to assess the environmental impacts of production and consumption across the EU and economic cost of improvement options. This enables prioritisation and planning to improve product supply chain impacts. It has specifically been developed and used for food.	http://ec.europa.eu/environment/ipp/pdf/eipro_report.pdf
CALCAS (Co-ordination Action for Innovation in Life-Cycle Analysis for Sustainability)	UK Sustainable Consumption Institute	The UK Sustainable Consumption Institute developed the Calcas food sector decision support tool and database to identify GHG hot spots across food and chemical (to account for agric business parts mainly) supply chains . The scope for this is mainly UK and it is aimed at business directly.	http://www.calcasproject.net/
Footprinter	Best Foot Forward	Software designed for businesses of any size to identify the carbon baseline and then identify the company's critical carbon risks	http://www.footprinter.com/
FB&A SMRS (Food Beverage and Agriculture Sustainability Measurement and Reporting Standard)	The Sustainability Consortium	This involves the development of a standardised methodology to evaluate and report product life cycle information for food, beverage, and agriculture products. The Sustainabilty Consortium is working across a number of different themes to drive scientific research and development of tools and standards for life cycle assessment of products	http://www.sustainabilityconsortium.org/
REAP (Resource and Energy Analysis Programme)	Stockholm Environment Institute	The REAP tool sits within a suite of models created at SEI. This methodology tracks product groups through every stage of their lifecycle and attributes the associated environmental consequences to 'end users' – government or households. It uses a binary Environmental Extended Input Output Model and is based on government statistics and socio-economic modeling.	http://www.resource-accounting.org.uk

This is a selection of tools and methodologies studied by the ISU. It is not comprehensive.

Writing team
David Barley
Lucy Holmes
Paul McMahon (lead author)

Project team
Charlotte Cawthorne
David Edwards
Jack Gibbs
Justin Mundy
Sophie Wood

Advisers
Peter Collecott
Patrick Holden
Tony Juniper
Dorothy Maxwell
Sir Graham Wynne

The Prince's Charities Foundation registered charity number 1127255

Contact Details

The Prince's Charities' International Sustainability Unit
Clarence House
London
SW1A 1BA

0207 024 2106
info@pcfisu.org

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